Formerly Utilized MED/AEC
Remedial Action Pr

Radiological Survey of the Seneca A
Romulus,

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U.S. Departme

Assistant Secretary
Division of Environmental Co
Washingt

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the Atomic Energy Commission (AEC) for determination of the condi

sites formerly utilized by the Manhattan Engineer District (MED) a

AEC for work involving the handling of radioactive materials. Sin

early 1940's, the control of over 100 sites that were no longer re

for nuclear programs has been returned to private industry or the

for unrestricted use. A search of MED and AEC records indicated t

some of these sites, documentation was insufficient to determine w

or not the decontamination work done at the time nuclear activitie

is adequate by current guidelines.

The work reported in this document was conducted by the following of the Health and Safety Research Division, Oak Ridge National Lab Oak Ridge, Tennessee:

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ABSTRACT

The results of a radiological survey of the Seneca Army Depot, Romulus, New York, are presented in this report. For a short period the early 1940s, eleven munition bunkers on this site were used for storage of approximately 2000 barrels of pitchblende ore. The survey was undertaken to characterize the radiological status of the bunker and to determine the extent of contamination in the area surrounding bunkers, in the surface waters in the vicinity of the bunkers, and along a rail spur leading into the area. It appears from the survey results that residual radioactivity resulting from the storage of th uranium ore is confined almost entirely to the interiors of eight of bunkers and to the outdoor areas near the entrances to these bunkers

INTRODUCTION

At the request of the Department of Energy (then ERDA), a radio cal survey was conducted at the Seneca Army Depot in Romulus, New Yo The Seneca Army Depot covers approximately 10,000 acres, and in a la part, consists of munition bunkers. Approximately 2000 barrels of p blende ore were stored in eleven of these bunkers during a short per

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inued up to the time of this survey. The bunkers are used for storag
nd are occupied for only brief periods by Army personnel. The presen
urvey was undertaken to characterize the radiological status of the unkers in which the ore was stored and to determine the extent of the pread of radioactivity in the area surrounding the bunkers, in the urface waters in the vicinity of the bunkers, and along a rail spur ver which the ore was transported to and from the facility.

The survey was conducted by three members of the Health and Safet esearch Division, Oak Ridge National Laboratory, during the period, eptember 10-23, 1976. The survey consisted of (1) direct readings of lpha and beta radiation levels on surfaces in each of the bunkers, (2 easurements of transferable alpha and beta radiation levels on surfac n the bunkers, (3) measurements of external gamma radiation levels in he bunkers and at one meter above the surface in the immediate vicini f the bunkers, (4) concentrations of uranium and some of its daughter roducts in soil samples taken in the vicinity of the bunkers, (5) rad nd radon daughter concentrations in air samples taken in the bunkers, 6) radioactivity in surface waters in the vicinity of the bunkers, an 7) radioactivity along the rail spur and loading docks which were use hen the ore was moved into and away from the site.

RADIOLOGICAL SURVEY TECHNIQUES

Measurement of Residual Alpha and Beta-Gamma Radiation Levels

flow proportional survey meters for measurement of alpha radiation, with Geiger-Mueller survey meters for measurement of beta-gamma rad These instruments are described in Appendix I. Survey meters were used to measure alpha radiation levels on the roof vents of the bun Both the average reading and the maximum reading are reported in Ta 1-12 for each area surveyed. Transferable radioactivity levels in buildings were measured using standard smear techniques and smear c described in Appendix I; the measurements are presented in Tables 1

Direct readings of alpha radioactivity which were less than 10 dpm/100 cm^2 are reported in Tables 1-12 as "<100." Transferable a radioactivity levels less than 10 dpm/100 cm^2, transferable beta-ga radioactivity less than 100 dpm/100 cm^2, and direct readings of bet gamma dose rates less than 0.03 mrad/hr, are reported in an analogo manner.

Measurement of Radon and Radon Daughter Concentrations in the Bunk

For the measurement of instantaneous radon concentrations in t air, samples were taken using evacuated 95-ml glass flasks (known a Lucas Chambers) coated inside with a uniform layer of zinc sulfide. Sample counting was delayed 3 to 4 hr to allow the radon daughters attain equilibrium. Scintillations from the zinc sulfide were then counted for 1000 sec with a system which utilizes a photomultiplier tube and associated electronics. A calibration performed at ORNL u

borne radon daughters in the bunkers. Air was pumped for five m at approximately 12 liters/min through a membrane filter with a pore size of 0.4 μ. The filter was counted using an alpha spect technique refined by Kerr.[1] This technique is described in Appe

Measurements of External Gamma Radiation Levels

External gamma radiation levels, which include natural back were measured with scintillation survey meters; these instrument described in Appendix I. Readings were taken in each bunker at meter above the floor at the center of each of the areas F1 thro (Fig. 1). Measurements also were made at one meter above the su the immediate vicinity of the bunkers and along the previously r rail spur (see Figs. 3 and 4).

Measurement of Radium and Uranium in the Soil

Soil samples were collected at several locations in the vic the bunkers (see Figs. 2A-2L), and a residue sample was taken fr drain trough in Bunker E0804. The samples were packaged in plas or bottles before being transported to Oak Ridge, where they wer for 24 hr at 110°C and then pulverized to a particle size of -3 (500 μm). Next, aliquots from each sample were transferred to bottles or petri dishes, weighed, and counted using a Ge(Li) de The spectra obtained were analyzed by computer techniques. Desc of the Ge(Li) detector and the soil counting techniques are giv

Water samples were collected from two drainage areas for deter
nation of radium, uranium, and thorium content. These samples were
taken at locations W9 and W10, shown in Fig. 3. The samples were a
at ORNL using sequential separation techniques.

SURVEY RESULTS

Background Measurements

Background measurements were taken in and around Bunker C0912, which has never been used for storage of radioactive materials. Th building is located approximately 1.5 miles from the bunkers in whi uranium ore was stored. Radiation measurements in this bunker were using the same techniques employed in bunkers used for ore storage; results are listed in Table 12. All direct readings of alpha radio in this building were less than 100 dpm/100 cm^2, and all transferab alpha readings were less than 10 dpm/100 cm^2. Direct readings of b gamma radiation levels in the bunker were less than 0.03 mrad/hr, a all smears showed less than 100 dpm/100 cm^2 for beta-gamma radiatio External gamma radiation measurements at one meter above the floor approximately 10 μR/hr throughout the bunker. Two measurements of instantaneous radon concentrations in the air in Bunker C0912 avera 1.2 pCi/liter (see Table 13), and the radon daughter concentration measured approximately 0.014 WL* (Table 14).

At one meter above the asphalt, grass, and soil surfaces outsi

0.8 pCi/g, respectively (see Tables 15 and 16).

Alpha and Beta-Gamma Radioactivity in the Bunkers

Direct readings of alpha and beta-gamma radiation levels (includi natural background) in Bunkers E0801-0811 are given in Tables 1 throug 11. Also presented are measurements of transferable radioactivity. I Bunkers E0801 (Table 1), E0802 (Table 2), and E0803 (Table 3), all measured radiation levels were similar to the background levels measu in Bunker C0912 (Table 12). There was no indication from these measu that radioactive materials had been stored in these three bunkers.

The highest levels of alpha contamination were detected in Bunke E0804 (Table 4), where direct readings as high as 1.3 x 10^5 dpm/100 c were found in small areas near the intersection of the floor and wall. In most areas of this building, alpha radioactivity was in the range o 200-2000 dpm/100 cm^2 by direct reading. Smear counts indicated that transferable alpha radioactivity in Bunker E0804 varied from backgrou levels up to approximately 430 dpm/100 cm^2. Direct readings of beta-gamma radiation in this bunker were as high as 16 mrad/hr in small, isolated spots, but varied from background levels to 0.2 mrad/hr in m areas of the bunker. Transferable beta-gamma radioactivity in Bunker E0804 ranged from background levels to 240 dpm/100 cm^2.

The pattern of alpha and beta contamination in the four bunkers E0805, E0806, E0807, and E0808 (see Tables 5-8) was somewhat similar

measured 5000-10,000 dpm/100 cm^2 in some isolated areas. However, one spot on the floor in Bunker E0806, the level by direct reading 7 x 10^4 dpm/100 cm^2. Transferable alpha was in the range of 10-40 cm^2 in most parts of these bunkers. Transferable beta was generall the range of 0-200 dpm/100 cm^2 but averaged approximately 2000 dpm/ cm^2 in one area of 15 m^2 (Fig. 1, block F15) in Bunker E0806. Dire readings of beta-gamma radiation in these buildings were usually be 0.1 mrad/hr but ranged as high as 4.57 mrad/hr in Bunker E0806 (Fig block F15).

In Bunkers E0809, E0810, and E0811 (Tables 9-11), direct readi of alpha radiation were well above 100 dpm/100 cm^2 in many areas. H all direct readings of alpha radioactivity were below 5000 dpm/100 and transferable alpha measurements were below 10 dpm/100 cm^2 in mo areas. Transferable beta-gamma radioactivity in these three buildi was below 100 dpm/100 cm^2 in most areas but was in the range of 100 dpm/100 cm^2 in isolated spots.

The exterior surfaces of the bunkers were uncontaminated excep the outsides of the vents (on the roofs) which showed some alpha co ination (see Table 18). Soil is built up around each bunker; only vent and the front of the structure are exposed. Direct readings alpha radioactivity taken on the outsides of the vents on Bunkers A and A0810, which are located about 4 miles from the bunkers in whic

E0801-0803 (see Table 14). The highest concentration measured in Bunker E0808) was about 3.5 times as high as the background ment taken in Bunker C0912. All radon daughter measurements w instantaneous measurements taken during the daytime and were t during a two-week period in September 1976.

The average concentration of radon measured in each of th E0801, E0802, and E0803 was near the background level of appro 1.2 pCi/liter measured in Bunker C0912. In the remaining bun radon concentrations were in the range of 2.2-6.4 pCi/liter (13). It should be noted that these measurements were taken ov period of time; radon and radon daughter levels in a building significantly over a period of several months.

The dose to individuals delivered by radon is small compa the dose delivered by its daughter products (about 500 times l equilibrium[2]). However, the measurement of radon concentratio buildings allows determination of the potential radon daughter assuming minimum ventilation. An increment of 1 pCi/liter in concentration in a poorly ventilated building might produce an as large as 0.0085 WL in the radon daughter concentration in t As an illustration, the highest concentration of radon in samp in Bunker E0809 was 6.4 pCi/liter. Hence, with poor ventilati

igh as 0.054 WL. This is only about 15% higher than the actual meas
adon daughter concentration.

Measurements of External Gamma Radiation

In each bunker, external gamma radiation readings were taken at
eter above the floor near the center of each block indicated in Fig.
ost readings (see Tables 1-11) were near the background level measur
n Bunker C0912. The highest readings were taken in Bunker E0811 and
ere about twice the background readings.

Measurements of external gamma radiation taken outdoors in the
mmediate vicinity of the bunkers are shown in Figs. 2A-2L. Except f
ome readings taken within 10-15 ft of the entrances to the bunkers,
easurements were at background level.

External gamma radiation levels were measured on Loading Dock 60
hich was used for the unloading of ore from rail cars, and on Loadin
ock 305, about 1000 ft north of Dock 600 (see Figs. 3 and 4). Exter
amma radiation on both docks and along the railroad tracks leading a
rom the docks was at background level. Readings of 15 μR/hr were
bserved along a drainage ditch near Dock 600 (Fig. 4). Some local
utcroppings of shale were observed in this area and may account for
hese readings.

Measurements of Radium Concentrations in Soil

the entrances to the bunkers where survey meters indicated that rad active contamination was highest.

The residue sample taken from the drain trough showed radium a uranium concentrations of 46,300 pCi/g and 67,070 pCi/g, respective The highest concentrations of radium in any soil sample collected ou doors was 7820 pCi/g in a sample taken near the entrance to Bunker E0804. Concentrations of radium and uranium in samples collected in vicinity of Bunkers E0801-0803 were near background levels.

Results of Water Sample Analyses

The concentrations of uranium, radium, and thorium in water samp taken from surface water in the vicinity of the bunkers are listed in Table 17, which also gives the maximum permissible concentrations [4] i water (MPC_w) for each isotope tested. Sample W9 was taken from a sma stream flowing near Bunker E0809, and Sample W10 is from a drainage ditch approximately 100 ft east of Bunker E0810 (see Fig. 3). In both samples, the concentration of each radionuclide tested was at least an order of magnitude below the MPC_w.

SUMMARY

The interior surfaces of at least eight of the bunkers have been contaminated with uranium ore; and, as a consequence, natural uranium and its daughters, including ^{226}Ra, may be found on these surfaces and on the out

ne fraction of equilibrium of ^{226}Ra for other contaminated surfaces on he site, it must be assumed (since uranium ore was handled on this ite) that a significant fraction of the alpha activity on the surfaces s due to ^{226}Ra. Since ANSI[5] and NRC[6] surface contamination limits for ^{226}Ra, among other nuclides, are 50 times more stringent than limits fo ^{238}U, it appears that the limits for ^{226}Ra should be applied to this ite. According to the NRC guidelines[6] (which are consistent with roposed ANSI standards[5]), average* and maximum* acceptable levels of ixed alpha contamination are 100 dpm/100 cm^2 and 300 dpm/100 cm^2, espectively, provided the principal contaminant is ^{226}Ra (see Appendix V). Transferable alpha contamination should not exceed 20 dpm/100 cm^2 nd transferable beta contamination limits should not exceed 1000 pm/100 cm^2. Average and maximum limits for beta-gamma dose rates at 1 m above a surface, according to NRC guidelines, are 0.2 mrad/hr and 1 rad/hr, respectively.

Direct alpha readings exceeded 300 dpm/100 cm^2 in some areas in ach of the eight bunkers E0804 through E0811, and transferable alpha ontamination exceeded 20 dpm/100 cm^2 at some points in E0804, E0805, 0806, E0807, E0809, and E0810. Transferable beta contamination xceeding 1000 dpm/100 cm^2 was measured in one area of the floor of unker E0806. Beta-gamma dose rates of 1.0 mrad/hr or higher were easured in Bunkers E0804 and E0806.

. Radon and radon daughter measurements taken over a short period e may not accurately reflect average annual conditions.

ne situation at this site bears some resemblance to that tered in Grand Junction, Colorado, where radium-bearing uranium ilings were used for private purposes, including construction of ce and commercial structures. At the request of the state of o, the U. S. Surgeon General has developed a set of guidelines in considering the need for remedial action in such cases. uidelines were adopted by ERDA as the basis for the Grand n Remedial Action Criteria, which has been codified as 10 CFR e Appendix IV). In considering the need for remedial action in es where the radon daughter concentration exceeds background, it mended that indoor radon daughter concentrations be determined average the results of six air samples each of at least 100- ration and taken at a minimum of four-week intervals throughout in a habitable area of a structure, or (2) utilizing some other approved by the Commission." For structures other than s, an observed average indoor radon daughter concentration 0.03 WL or greater above background will qualify the structure deration by ERDA and regulatory authorities of the need for action. If it is determined that the Surgeon General's

asurements made during this survey indicate the need for continued mpling over periods as recommended in 10 CFR 712, since measured rado ughter concentrations were found to exceed background levels by 0.03 or more in some of the bunkers. It should be pointed out that the nkers are used for storage and are occupied for only brief periods of me, so that the measured radon daughter levels at present do not pear to constitute a health hazard. However, there is no guarantee at the bunkers will not be occupied for longer periods of time at som ture date, and the average radon daughter levels may be significantly gher than the instantaneous concentrations measured during the survey

External gamma radiation levels at one meter above the floor in th nkers ranged from background levels (about 10 μR/hr) up to 21 μR/hr, th highest levels being measured in Bunkers E0810 and E0811. In some ses, external gamma radiation readings taken outdoors near the bunker trances were above background levels. The highest external gamma diation reading taken at one meter above the surface on the site was μR/hr, near the entrance to Bunker E0806. (However, an open-window M meter reading taken at one cm above the ground in a small area near e entrance of Bunker E0804 revealed beta-gamma radiation of 27 ad/hr.) All other external gamma radiation readings taken in the cinity of the bunkers and along the railroad tracks where the uranium e was loaded were in the range of 8-15 μR/hr.

Concentrations of radium as high as 7820 pCi/g were found in soil

... order of magnitude below th
maximum permissible concentrations.

An evaluation has been made of current radiation exposures a
Seneca Army Depot, and is presented in Appendix V (page 101) of t
report. The purpose of this evaluation is to present information
will permit the reader to compare current radiation exposures fro
site to normal background exposures for that part of New York, as
as to scientifically based guideline values established for the protection of radiation workers and members of the general public.

1. G. D. Kerr, *Measurement of Radon Progeny Concentrations in Ai by Alpha-Particle Spectroscopy*, ORNL/TM-4924, (July 1975).

2. M. Eisenbud, *Environmental Radioactivity*, (pp. 158-159,) McGr New York; 1963.

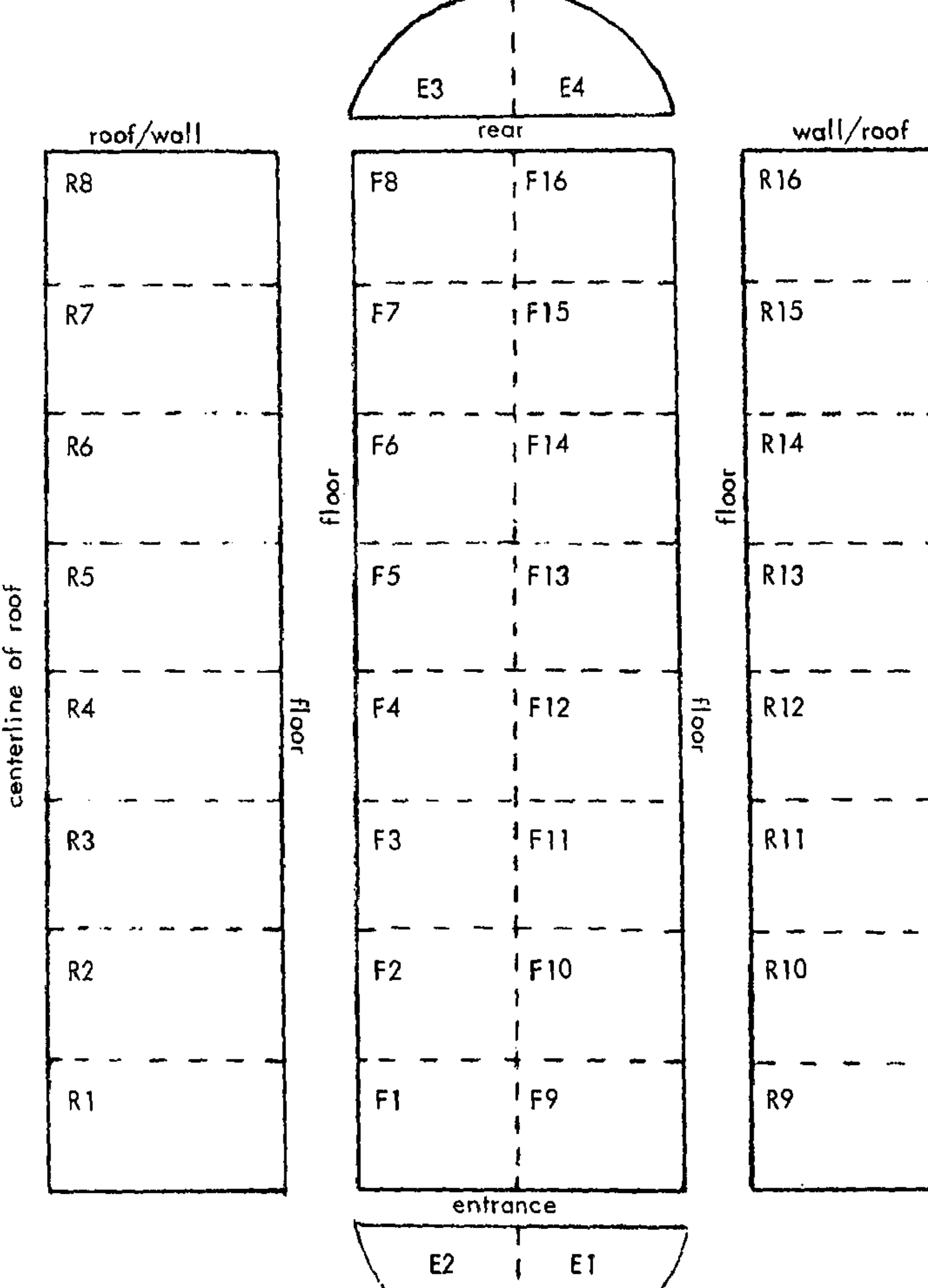
3. A. Toth, "Determining the Respiratory Dosage from RaA, RaB, a Inhaled by the Population in Hungary," *Health Phys.* 23, 281 (1972).

4. Code of Federal Regulations, Title 10, Part 20, *Standards for tection Against Radiation*, Appendix B.

5. Proposed American National Standard, ANSI N328-197, *Control o Radioactive Surface Contamination on Materials, Equipment, an Facilities to be Released for Uncontrolled Use*, 1976.

6. *Guidelines for Decontamination of Facilities and Equipment Pr to Release for Unrestricted Use or Termination of Licenses fo Byproduct, Source, or Special Nuclear Material*, USNRC, Decemb 1975.

7. Grand Junction Remedial Action Criteria, 10 CFR; Part 712, Fe Register, Vol. 41, No. 252-Thursday, December 30, 1976.


E3
E4
rear
roof/wall
wall/roof
R8
R7
R6
R5
R4
R3
R2
R1
F8
F7
F6
F5
F4
F3
F2
F1
F16
F15
F14
F13
F12
F11
F10
F9
R16
R15
R14
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centerline of roof
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floor
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floor
entrance
E2
E1

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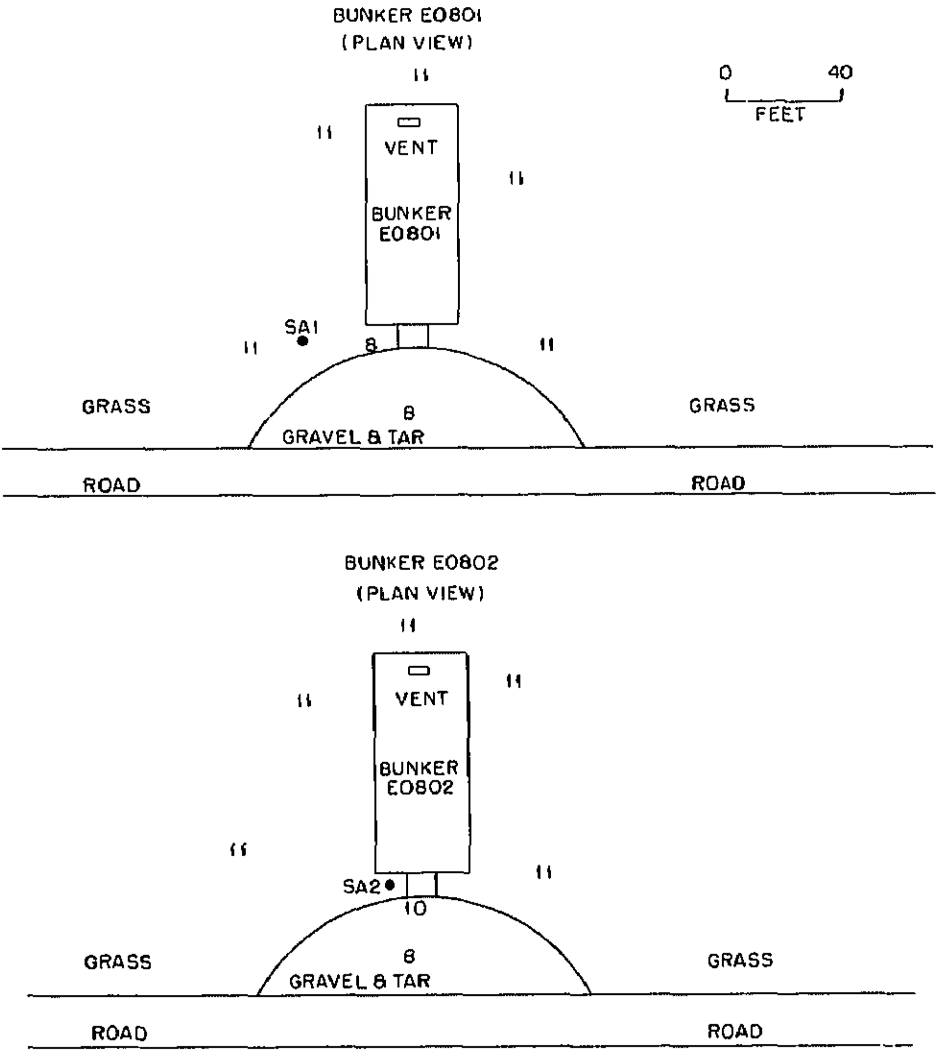
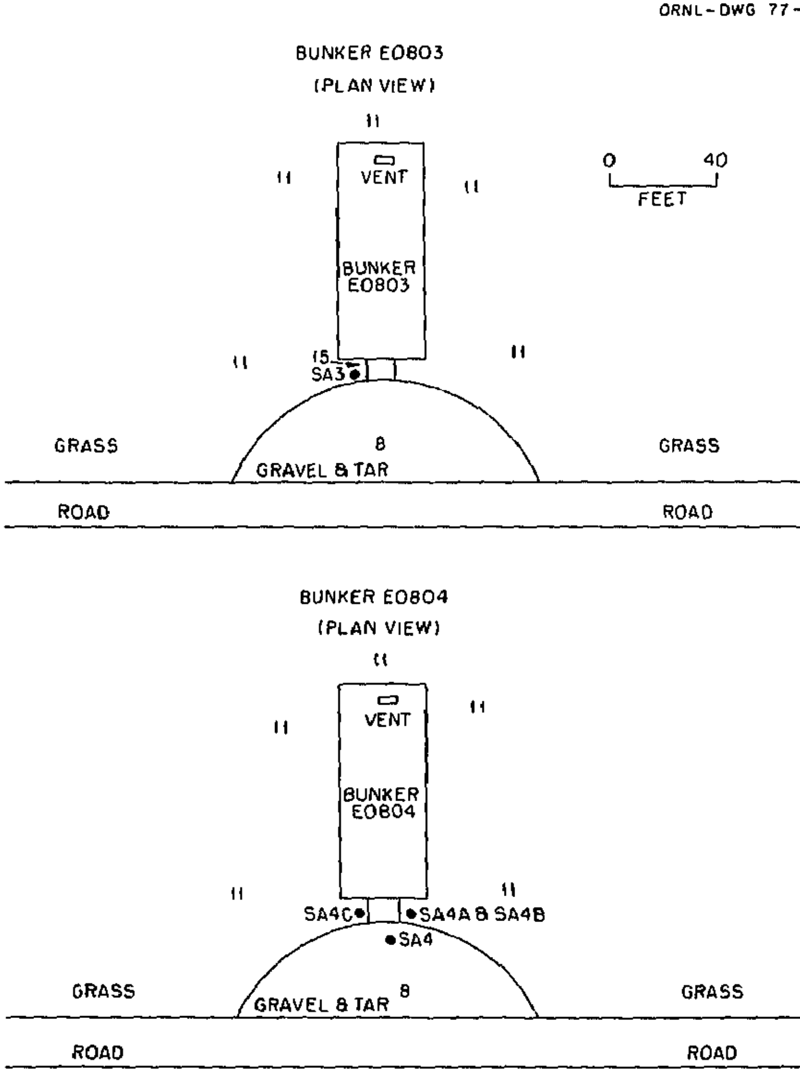


Figs. 2A & 2B. External gamma radiation readings (in μR/hr).

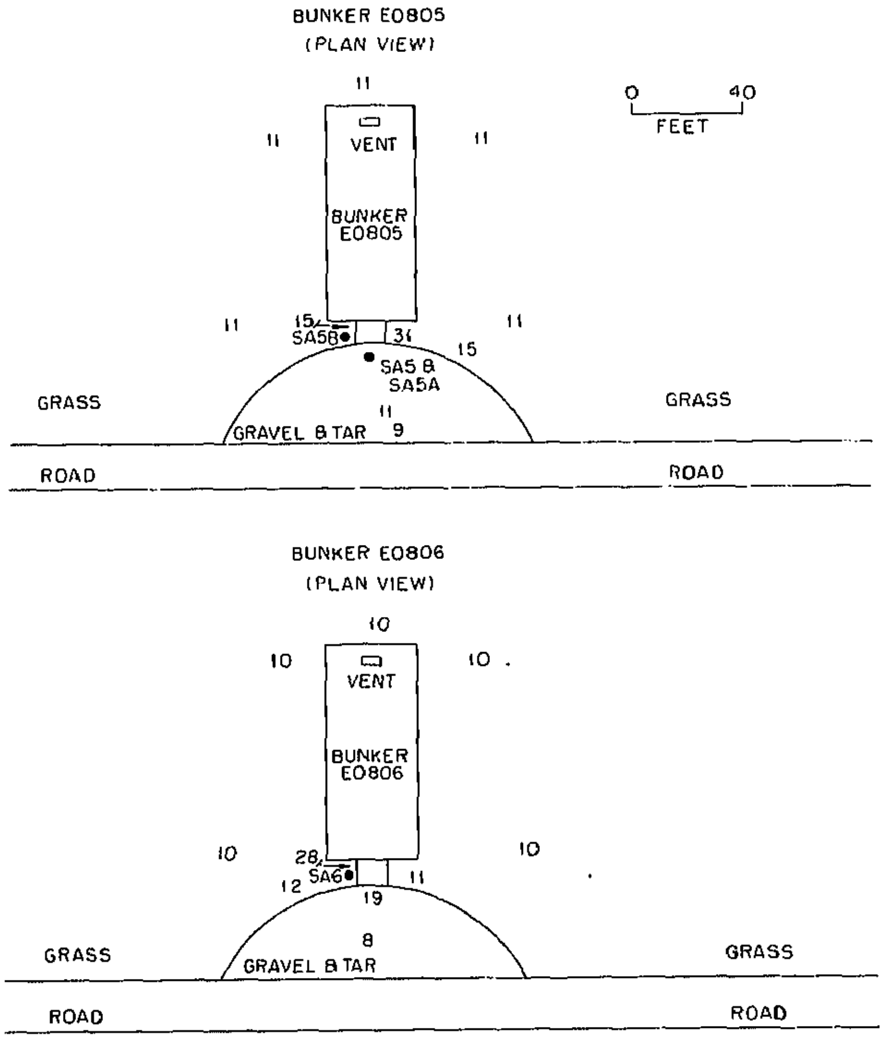
Note: Location of soil samples denoted by number and SA prefix.



Figs. 2C & 2D. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by

ORNL-DWG 77-5164



Figs. 2E & 2F. External gamma radiation readings (in μR/hr).

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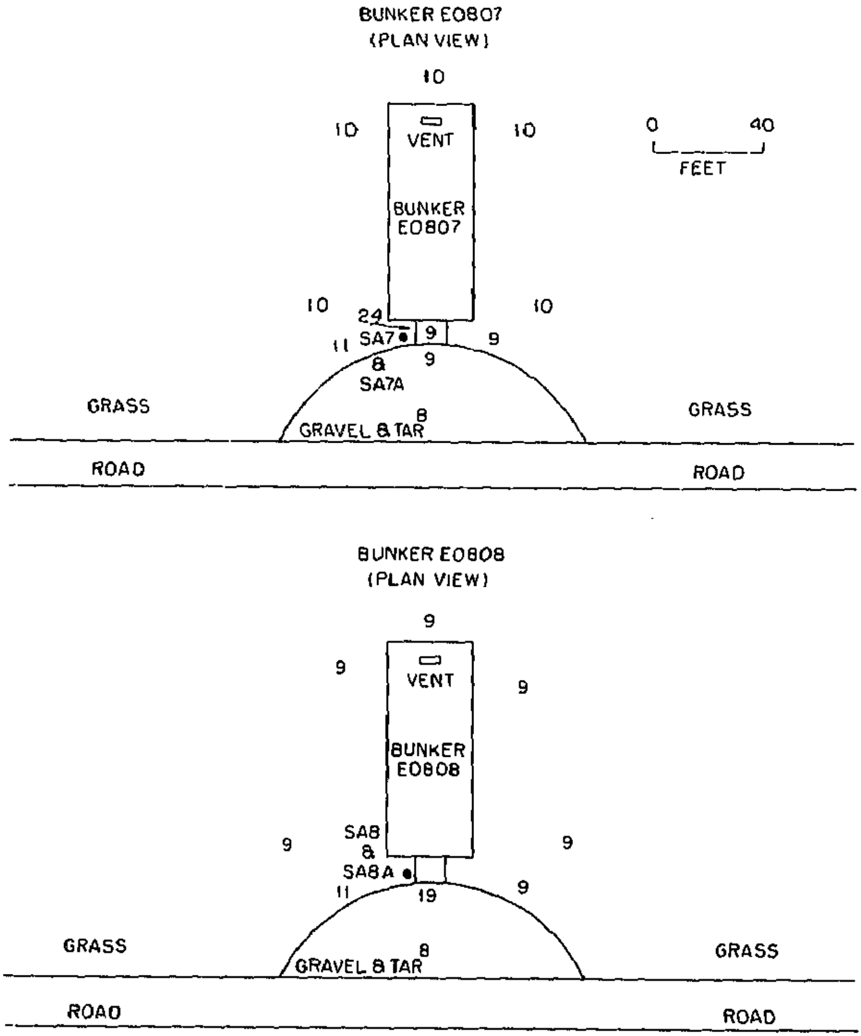
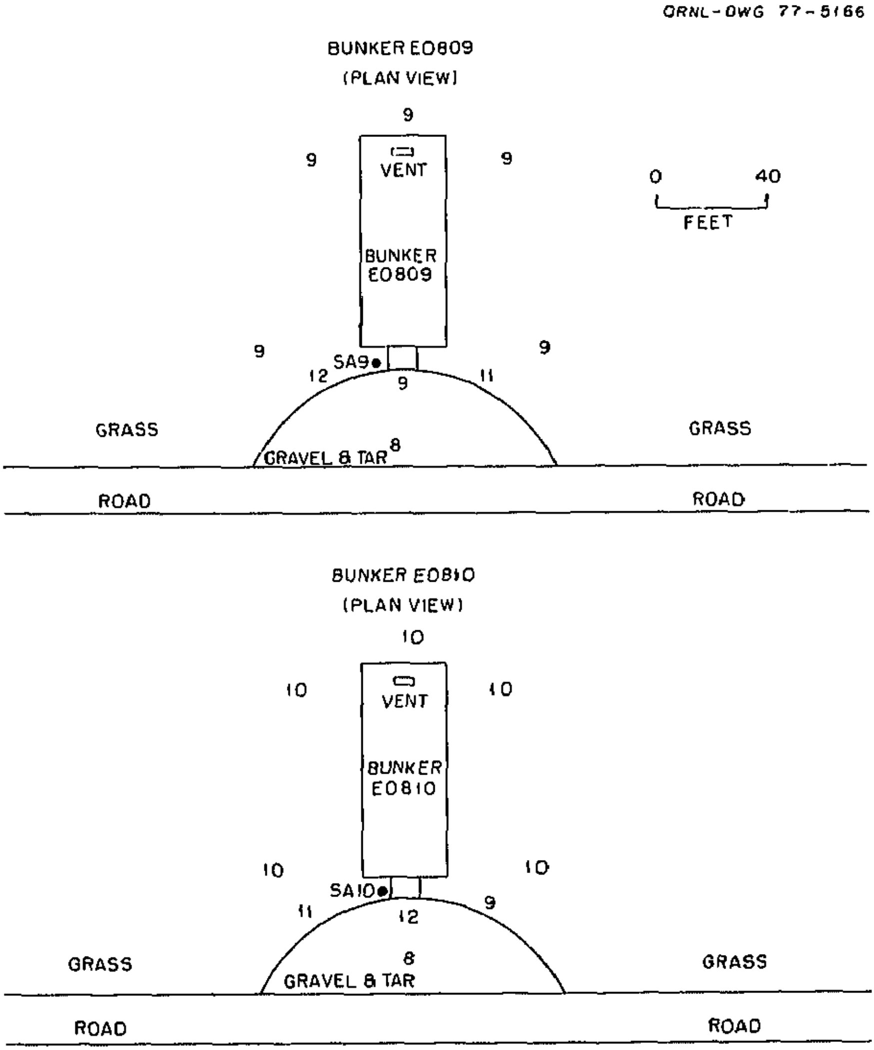
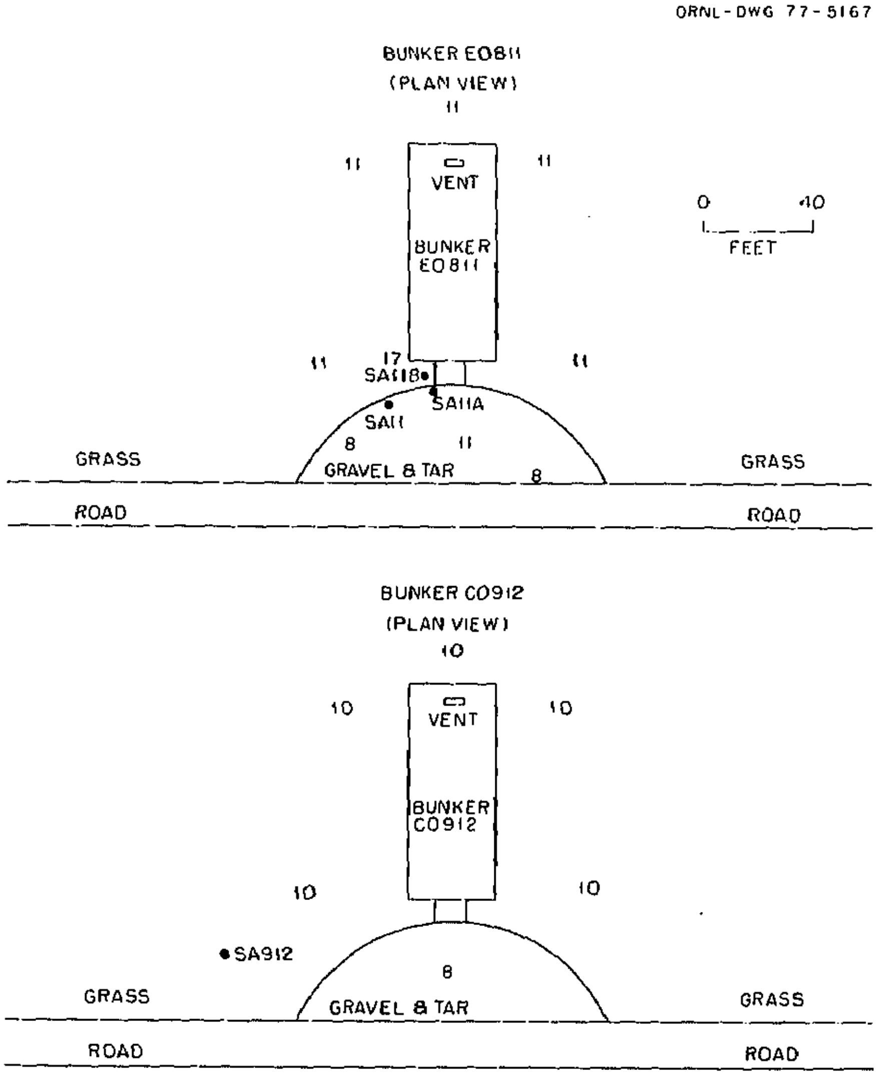


Figs. 2G & 2H. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.



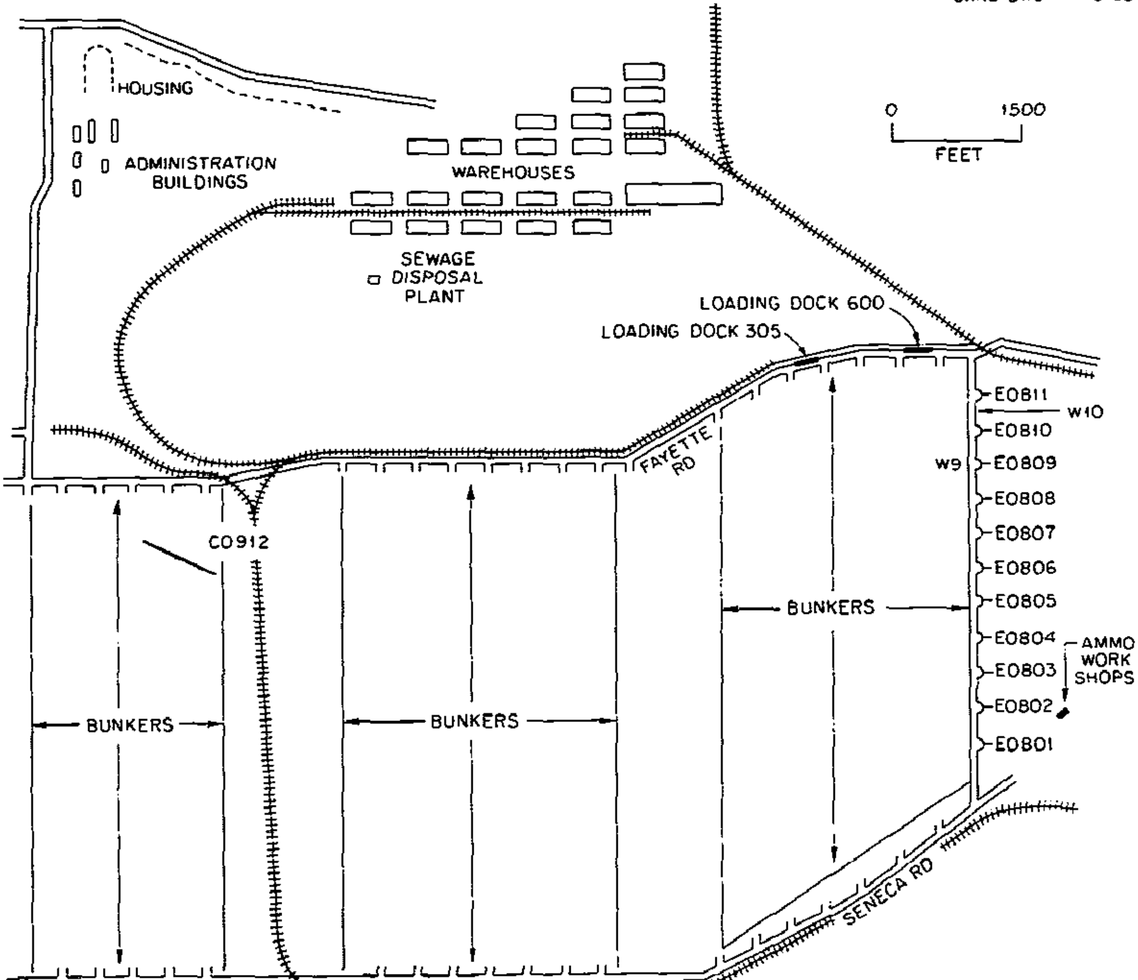
Figs. 2I & 2J. External gamma radiation readings (in μR/hr).



Figs. 2K & 2L. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.

ORNL-DWG 77-5160



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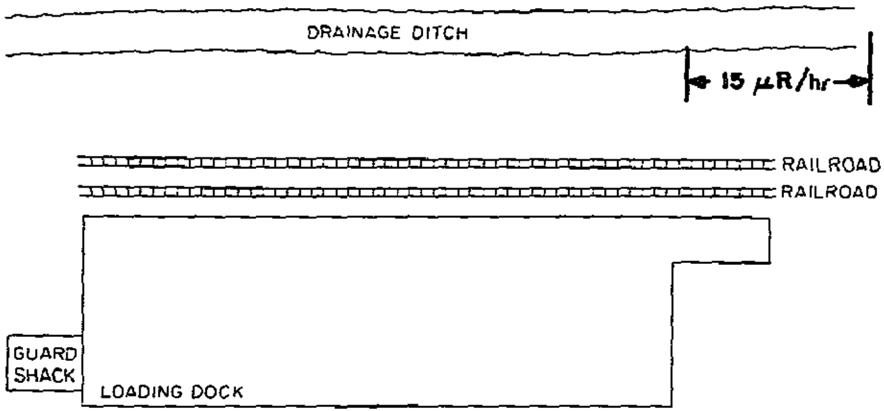

Fig. 4. Loading Dock 600 and nearby landmarks.

Table 1. Alpha, beta, and gamma radiation in Bunker E0801

cation	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)
			Floor			
F1	<100	<100	<10	<0.03	<0.03	<100
F2	<100	<100	<10	<0.03	<0.03	<100
F3	<100	<100	<10	<0.03	<0.03	<100
F4	<100	<100	<10	<0.03	<0.03	<100
F5	<100	<100	<10	<0.03	<0.03	<100
F6	<100	<100	<10	<0.03	<0.03	<100
F7	<100	<100	<10	<0.03	<0.03	<100
F8	<100	<100	<10	<0.03	<0.03	<100
F9	<100	<100	<10	<0.03	<0.03	<100
F10	<100	<100	<10	<0.03	<0.03	<100
F11	<100	<100	<10	<0.03	<0.03	<100
F12	<100	<100	<10	<0.03	<0.03	<100
F13	<100	<100	<10	<0.03	<0.03	<100
F14	<100	<100	<10	<0.03	<0.03	<100
F15	<100	<100	<10	<0.03	<0.03	<100
F16	<100	<100	<10	<0.03	<0.03	<100
			Roof and side walls			
R1	<100	<100	<10	<0.03	<0.03	<100
R2	<100	<100	<10	<0.03	<0.03	<100
R3	<100	<100	<10	<0.03	<0.03	<100
R4	<100	<100	<10	<0.03	<0.03	<100
R5	<100	<100	<10	<0.03	<0.03	<100
R6	<100	<100	<10	<0.03	<0.03	<100
R7	<100	<100	<10	<0.03	<0.03	<100
R8	<100	<100	<10	<0.03	<0.03	<100
R9	<100	<100	<10	<0.03	<0.03	<100
R10	<100	<100	<10	<0.03	<0.03	<100
R11	<100	<100	<10	<0.03	<0.03	<100

Table 1 (cont.). Alpha, beta, and gamma radiation in Bunker E0801

...on	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	Exte...
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
				End walls			
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	

...es gamma rays.

Table 2. Alpha, beta, and gamma radiation in Bunker E0802

cation	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)
			Floor			
F1	<100	<100	<10	<0.03	<0.03	<100
F2	<100	<100	<10	<0.03	<0.03	<100
F3	<100	<100	<10	<0.03	<0.03	<100
F4	<100	<100	<10	<0.03	<0.03	<100
F5	<100	<100	<10	<0.03	<0.03	<100
F6	<100	<100	<10	<0.03	<0.03	<100
F7	<100	<100	<10	<0.03	<0.03	<100
F8	<100	<100	<10	<0.03	<0.03	<100
F9	<100	<100	<10	<0.03	<0.03	<100
F10	<100	<100	<10	<0.03	<0.03	<100
F11	<100	<100	<10	<0.03	<0.03	<100
F12	<100	<100	<10	<0.03	<0.03	<100
F13	<100	<100	<10	<0.03	<0.03	<100
F14	<100	<100	<10	<0.03	<0.03	<100
F15	<100	<100	<10	<0.03	<0.03	<100
F16	<100	<100	<10	<0.03	<0.03	<100
			Roof and side walls			
R1	<100	<100	<10	<0.03	<0.03	<100
R2	<100	<100	<10	<0.03	<0.03	<100
R3	<100	<100	<10	<0.03	<0.03	<100
R4	<100	<100	<10	<0.03	<0.03	<100
R5	<100	<100	<10	<0.03	<0.03	<100
R6	<100	<100	<10	<0.03	<0.03	<100
R7	<100	<100	<10	<0.03	<0.03	<100
R8	<100	<100	<10	<0.03	<0.03	<100
R9	<100	<100	<10	<0.03	<0.03	<100
R10	<100	<100	<10	<0.03	<0.03	<100

Table 2 (cont.). Alpha, beta, and gamma radiation in Bunker E0802

n	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	Exter a (
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
			End walls				
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	

es gamma rays.

Table 3. Alpha, beta, and gamma radiation in Bunker E0803

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)
			Floor			
F1	<100	<100	<10	<0.03	<0.03	<100
F2	<100	<100	<10	<0.03	<0.03	<100
F3	<100	<100	<10	<0.03	<0.03	<100
F4	<100	<100	<10	<0.03	<0.03	<100
F5	<100	<100	<10	<0.03	<0.03	<100
F6	<100	<100	<10	<0.03	<0.03	<100
F7	<100	<100	<10	<0.03	<0.03	<100
F8	<100	<100	<10	<0.03	<0.03	<100
F9	<100	<100	<10	<0.03	<0.03	<100
F10	<100	<100	<10	<0.03	<0.03	<100
F11	<100	<100	<10	<0.03	<0.03	<100
F12	<100	<100	<10	<0.03	<0.03	<100
F13	<100	<100	<10	<0.03	<0.03	<100
F14	<100	<100	<10	<0.03	<0.03	<100
F15	<100	<100	<10	<0.03	<0.03	<100
F16	<100	<100	<10	<0.03	<0.03	<100
			Roof and side walls			
1	<100	<100	<10	<0.03	<0.03	<100
2	<100	<100	<10	<0.03	<0.03	<100
3	<100	<100	<10	<0.03	<0.03	<100
4	<100	<100	<10	<0.03	<0.03	<100
5	<100	<100	<10	<0.03	<0.03	<100
6	<100	<100	<10	<0.03	<0.03	<100
7	<100	<100	<10	<0.03	<0.03	<100
8	<100	<100	<10	<0.03	<0.03	<100
9	<100	<100	<10	<0.03	<0.03	<100
10	<100	<100	<10	<0.03	<0.03	<100
11	<100	<100	<10	<0.03	<0.03	<100
12	<100	<100	<10	<0.03	<0.03	<100

Table 3 (cont.). Alpha, beta, and gamma radiation in Bunker E0803

n	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	Exte
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
				End walls			
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	
	<100	<100	<10	<0.03	<0.03	<100	

es gamma rays.

Table 4. Alpha, beta, and gamma radiation in Bunker 20804

Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External at 1 (μR/h
Floor						
1350	18,000	72	0.09	16.0	<100	12
750	2,900	66	0.09	0.92	<100	12
1000	3,000	88	0.10	2.28	<100	12
1200	9,000	88	0.10	3.43	<100	12
1250	10,000	80	0.17	5.71	<100	12
1650	70,000	102	0.17	4.57	<100	12
750	1,500	62	0.09	0.23	<100	10
750	2,800	20	0.09	0.17	<100	10
1500	4,000	44	0.09	2.86	<100	12
1500	8,000	54	0.12	0.86	<100	12
2000	6,000	56	0.12	0.29	<100	12
1200	9,000	46	0.09	0.63	<100	12
700	2,000	42	0.09	0.14	<100	11
600	2,000	30	0.09	0.12	<100	11
600	1,500	48	0.06	0.17	<100	11
450	2,000	18	0.06	0.17	<100	11
Roof and side walls						
200	1,000	240	0.05	0.12	240	
200	1,000	48	0.05	0.12	240	
200	1,000	150	0.05	0.12	240	
700	20,000	132	0.05	1.03	240	
700	20,000	144	0.05	1.03	<100	
700	130,000	432	0.05	4.57	200	
200	1,000	<10	<0.03	0.12	<100	
200	1,000	<10	<0.03	0.12	<100	
200	500	<10	<0.03	0.12	<100	
200	500	<10	<0.03	0.12	<100	
200	500	<10	<0.03	0.12	<100	
200	500	<10	<0.03	0.12	<100	

Table 4 (cont.). Alpha, beta, and gamma radiation in Bunker E0804

Location	Direct alpha (dpm/100 cm^2) average	Direct alpha (dpm/100 cm^2) maximum	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] (mrad/hr) average	Beta-gamma dose rate[a] (mrad/hr) maximum	Transferable beta (dpm/100 cm^2)
R12	200	500	<10	<0.03	0.12	<100
R13	200	500	<10	<0.03	0.12	<100
R14	200	500	<10	<0.03	0.12	<100
R15	200	500	<10	<0.03	0.12	<100
R16	200	500	<10	<0.03	0.12	<100
End walls						
E1	200	500	<10	<0.03	<0.03	<100
E2	200	500	<10	<0.03	<0.03	<100
E3	200	500	<10	<0.03	<0.03	<100
E4	200	500	<10	<0.03	<0.03	<100

[a]Includes gamma rays.

cation	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)
				Floor		
F 1	400	1500	<10	0.10	0.14	<100
F 2	450	1200	<10	0.07	0.12	<100
F 3	150	700	<10	0.10	0.34	<100
F 4	250	1100	36	0.09	0.20	<100
F 5	200	600	<10	0.09	0.17	<100
F 6	250	800	<10	0.09	0.46	<100
F 7	250	1600	<10	0.09	0.86	<100
F 8	500	6000	<10	0.10	0.69	<100
F 9	300	1200	<10	0.07	0.09	<100
F10	300	900	<10	0.06	0.12	<100
F11	300	700	<10	0.06	0.09	<100
F12	200	500	<10	0.07	0.12	<100
F13	200	4000	<10	0.12	0.26	<100
F14	150	800	<10	0.10	0.17	<100
F15	150	1800	<10	0.10	0.20	<100
F16	400	3000	48	0.12	0.57	<100
				Roof & side walls		
R 1	200	400	<10	0.09	0.18	<100
R 2	200	400	<10	0.09	0.18	<100
R 3	200	400	<10	0.09	0.18	<100
R 4	200	400	<10	0.09	0.18	<100
R 5	200	400	<10	0.09	0.18	<100
R 6	200	400	<10	0.09	0.18	<100
R 7	200	400	<10	0.09	0.74	<100
R 8	200	400	<10	0.09	0.18	<100
R 9	200	400	<10	0.09	0.18	<100

Table 5 (cont.). Alpha, beta and gamma radiation in Bunker E0805

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)
R10	200	400	<10	0.09	0.18	<100
R11	200	400	<10	0.09	0.18	<100
R12	200	400	<10	0.09	0.18	<100
R13	200	400	<10	0.09	0.18	<100
R14	200	400	<10	0.09	0.18	<100
R15	200	400	<10	0.09	0.18	<100
R16	200	400	<10	0.09	0.18	<100
				End walls		
E 1	200	400	<10	0.09	0.18	<100
E 2	200	400	<10	0.09	0.18	<100
E 3	200	400	<10	0.09	0.18	<100
E 4	200	400	<10	0.09	0.18	<100

[a] Includes gamma rays.

Table 6. Alpha, beta and gamma radiation in Bunker E0806

ation	Direct alpha average	Direct alpha maximum	Transferable alpha	Beta-gamma dose rate[a] average	Beta-gamma dose rate[a] maximum	Transferable beta	E
	(dpm/100 cm^2)		(dpm/100 cm^2)	(mrad/hr)		(dpm/100 cm^2)	
				Floor			
F 1	300	800	11	0.05	0.12	<100	
F 2	500	2,200	<10	0.06	0.20	102	
F 3	200	5,000	<10	0.07	0.34	<100	
F 4	300	800	<10	0.06	0.12	<100	
F 5	300	1,000	13	0.05	0.12	<100	
F 6	300	2,500	<10	0.06	0.20	<100	
F 7	300	1,500	15	0.06	0.14	<100	
F 8	400	3,000	13	0.07	0.23	<100	
F 9	800	2,000	14	0.07	0.17	<100	
F10	800	3,000	<10	0.07	0.14	<100	
F11	500	3,000	18	0.07	0.20	<100	
F12	450	2,500	22	0.06	0.15	<100	
F13	450	2,500	22	0.06	0.14	<100	
F14	500	6,000	32	0.06	0.40	136	
F15	1100	70,000	2530	0.09	4.57	2360	
F16	350	3,000	28	0.06	0.20	<100	
				Roof & side walls			
R 1	300	400	<10	<0.03	<0.03	<100	
R 2	300	400	<10	<0.03	<0.03	<100	
R 3	300	400	<10	<0.03	<0.03	<100	
R 4	300	400	<10	<0.03	<0.03	<100	
R 5	300	400	<10	<0.03	<0.03	<100	
R 6	300	800	11	<0.03	<0.03	<100	
R 7	300	800	<10	<0.03	<0.03	<100	
R 8	300	500	13	<0.03	<0.03	<100	

Table 6 (cont.). Alpha, beta and gamma radiation in Bunker E0806

Location	Direct alpha (dpm/100 cm^2)		Transferable alpha (dpm/1oo cm^2)	Beta-gamma dose rate[a] (mrad/hr)		Transferable beta (dpm/100 cm^2)
	average	maximum		average	maximum	
R 9	300	600	<10	<0.03	<0.03	<100
R10	300	400	<10	<0.03	<0.03	<100
R11	300	400	<10	<0.03	<0.03	<100
R12	300	400	<10	<0.03	<0.03	<100
R13	300	400	<10	<0.03	<0.03	<100
R14	300	900	10	<0.03	<0.03	<100
R15	300	1500	12	<0.03	<0.03	<100
R16	300	1000	10	<0.03	<0.03	<100
			End walls			
E 1			<10			<100
E 2			<10			<100
E 3			<10			<100
E 4			<10			<100

[a]Includes gamma rays.

Table 7. Alpha, beta and gamma radiation in Bunker E0S07

Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[2] average (mrad/hr)	Beta-gamma dose rate[2] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External g at 1 m (μR/hr
			Floor			
125	650	<10	0.03	0.09	<100	12
100	2500	38	0.03	0.10	<100	14
100	600	<10	0.03	0.06	<100	12
100	1600	<10	0.03	0.14	<100	12
100	1200	<10	0.03	0.06	<100	14
100	500	<10	0.03	0.05	<100	14
150	300	<10	0.06	0.09	<100	10
250	9000	<10	0.07	0.68	<100	10
150	200	<10	0.05	0.09	<100	10
150	300	<10	0.05	0.09	<100	10
100	300	<10	0.05	0.09	<100	10
200	2500	<10	0.05	0.20	<100	10
300	1300	<10	0.05	0.09	<100	10
150	700	<10	0.05	0.09	<100	10
250	2500	<10	0.04	0.14	<100	10
750	8000	<10	0.03	0.68	<100	10
			Roof & side walls			
125	200	<10	<0.03	<0.03	<100	
125	200	<10	<0.03	<0.03	<100	
125	200	<10	<0.03	<0.03	<100	
125	200	<10	<0.03	<0.03	<100	
125	200	<10	<0.03	<0.03	<100	
125	200	<10	<0.03	<0.03	<100	
125	200	<10	<0.03	<0.03	<100	
125	200	<10	<0.03	<0.03	<100	

Table 7 (cont.). Alpha, beta and gamma radiation in Bunker E08

Location	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable b (dpm/100 cm
R10	125	200	<10	<0.03	<0.03	<100
R11	125	200	<10	<0.03	<0.03	<100
R12	125	200	<10	<0.03	<0.03	<100
R13	125	300	<10	<0.03	<0.03	<100
R14	125	200	<10	<0.03	<0.03	<100
R15	125	200	<10	<0.03	<0.03	<100
R16	125	200	<10	<0.03	<0.03	<100
				End walls		
E 1	<100	250		<0.03	<0.03	<100
E 2	<100	200		<0.03	<0.03	<100
E 3	<100	150		<0.03	<0.03	<100
E 4	<100	200		<0.03	<0.03	<100

[a]Includes gamma rays

Table 8. Alpha, beta and gamma radiation in Bunker E0808

Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External ga at 1 m (μR/hr)
			Floor			
125	300	<10	0.03	0.10	<100	10
175	400	<10	0.05	0.12	<100	15
250	450	<10	0.04	0.12	<100	15
300	2000	<10	0.06	0.40	<100	15
150	300	<10	0.04	0.10	<100	15
250	500	<10	0.04	0.12	<100	12
250	500	<10	0.05	0.12	<100	10
300	2000	<10	0.06	0.17	<100	10
150	300	<10	0.05	0.14	<100	10
250	600	<10	0.05	0.17	<100	15
300	900	<10	0.03	0.05	187	12
450	3000	<10	0.06	0.10	<100	15
250	8000	<10	0.06	0.57	<100	15
450	2100	<10	0.04	0.10	136	12
250	800	<10	0.03	0.06	<100	15
350	1800	<10	0.06	0.09	<100	12
			Roof & side walls			
150	360	<10	<0.03	<0.03	<100	
150	360	<10	<0.03	<0.03	<100	
150	360	<10	<0.03	<0.03	<100	
150	360	<10	<0.03	<0.03	170	
150	360	<10	<0.03	<0.03	<100	
150	360	<10	<0.03	<0.03	<100	
150	360	<10	<0.03	<0.03	<100	
150	360	<10	<0.03	<0.03	<100	

Table 8 (cont.). Alpha, beta and gamma radiation in Bunker E0808

Location	Direct alpha (dpm/100 cm²)		Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] (mrad/hr)		Transferable beta (dpm/100 cm^2)
	average	maximum		average	maximum	
R10	150	360	<10	<0.03	<0.03	109
R11	150	360	<10	<0.03	<0.03	109
R12	150	360	<10	<0.03	<0.03	109
R13	150	360	<10	<0.03	<0.03	109
R14	150	360	<10	<0.03	<0.03	109
R15	150	360	<10	<0.03	<0.03	109
R16	150	360	<10	<0.03	<0.03	<100
				End walls		
E 1	75	300	<10	<0.03	<0.03	<100
E 2	150	360	<10	<0.03	<0.03	<100
E 3	150	360	<10	<0.03	<0.03	<100
E 4	150	360	<10	<0.03	<0.03	<100

[a]Includes gamma rays.

Table 9. Alpha, beta and gamma radiation in Bunker E0809

Location	Direct alpha average	Direct alpha maximum	Transferable alpha	Beta-gamma dose rate[a] average	Beta-gamma dose rate[a] maximum	Transferable beta
	(dpm/100 cm^2)		(dpm/100 cm^2)	(mrad/hr)		(dpm/100 cm^2)
				Floor		
F 1	350	2100	<10	0.05	0.20	<100
F 2	200	500	<10	0.10	0.12	<100
F 3	300	500	<10	0.03	0.09	<100
F 4	250	500	13	0.06	0.12	<100
F 5	250	500	15	0.05	0.09	102
F 6	500	1200	13	0.03	0.11	<100
F 7	900	1800	13	0.06	0.14	<100
F 8	300	1200	11	0.03	0.12	<100
F 9	250	600	<10	0.05	0.12	<100
F10	200	950	38	0.06	0.14	<100
F11	200	600	<10	0.05	0.13	<100
F12	400	1300	28	0.06	0.16	<100
F13	250	900	17	0.06	0.14	<100
F14	400	1100	21	0.07	0.17	<100
F15	400	1400	34	0.05	0.18	<100
F16	450	1400	36	0.07	0.23	<100
				Roof & side walls		
R 1	100	300	<10	<0.03	<0.03	<100
R 2	100	300	<10	<0.03	<0.03	<100
R 3	100	300	13	<0.03	<0.03	<100
R 4	100	300	<10	<0.03	<0.03	<100
R 5	100	300	<10	<0.03	<0.03	<100
R 6	100	300	<10	<0.03	<0.03	<100
R 7	100	300	<10	<0.03	[illegible]	[illegible]

Table 9 (cont.). Alpha, beta and gamma radiation in Bunker E0809

Location	Direct alpha (dpm/100 cm^2)		Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] (mrad/hr)		Transferable beta (dpm/100 cm^2)
	average	maximum		average	maximum	
R10	100	300	<10	<0.03	<0.03	<100
R11	100	300	<10	<0.03	<0.03	102
R12	100	300	<10	<0.03	<0.03	<100
R13	100	300	<10	<0.03	<0.03	<100
R14	100	300	<10	<0.03	<0.03	<100
R15	100	300	<10	<0.03	<0.03	<100
R16	100	300	<10	<0.03	<0.03	<100
				End walls		
E 1	150	250	<10	<0.03	<0.03	<100
E 2	150	250	<10	<0.03	<0.03	<100
E 3	150	300	<10	<0.03	<0.03	<100
E 4	150	300	<10	<0.03	<0.03	<100

[a]Includes gamma rays.

ation	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	Ex
				Floor			
1	250	600	<10	0.03	0.05	<100	
2	450	2000	<10	0.05	0.09	<100	
3	750	4000	<10	0.05	0.69	170	
4	450	600	<10	0.03	0.06	<100	
5	350	1400	<10	0.04	0.09	<100	
6	350	1200	<10	0.03	0.09	<100	
7	650	1600	14	0.05	0.11	<100	
8	350	3000	<10	0.03	0.29	<100	
9	150	400	<10	0.03	0.09	102	
10	350	900	<10	0.03	0.11	119	
11	450	1400	<10	0.03	0.14	102	
12	500	900	<10	0.03	0.10	119	
13	450	1000	<10	0.03	0.09	119	
14	400	700	<10	0.03	0.03	<100	
15	1000	2500	<10	0.06	0.11	170	
16	650	1500	22	0.05	0.69	204	
				Roof and side walls			
R 1	<100	150	<10	<0.03	<0.03	136	
R 2	<100	150	<10	<0.03	<0.03	<100	
R 3	<100	150	<10	<0.03	<0.03	<100	
R 4	<100	150	<10	<0.03	<0.03	<100	
R 5	<100	150	<10	<0.03	<0.03	<100	
R 6	<100	150	<10	<0.03	<0.03	<100	
R 7	<100	150	<10	<0.03	<0.03	136	
R 8	<100	150	<10	<0.03	<0.03	170	
R 9	<100	150	<10	<0.03	<0.03	155	

Table 10 (cont.). Alpha, beta and gamma radiation in Bunker E0810

Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External at 1 (μR/
<100	150	<10	<0.03	<0.03	<100	
<100	150	<10	<0.05	<0.03	136	
<100	150	<10	<0.03	<0.03	136	
<100	150	<10	<0.03	<0.03	<100	
<100	150	<10	<0.03	<0.03	<100	
<100	150	<10	<0.03	<0.03	<100	
<100	150	<10	<0.03	<0.03	<100	
			End walls			
<100	200	<10	<0.03	<0.03	153	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	

amma rays.

Table 11. Alpha, beta and gamma radiation in Bunker E0811

Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External g at 1 m (μR/hr
			Floor			
550	800	<10	0.03	0.03	<100	19
550	1600	<10	0.06	0.15	<100	19
550	1000	<10	0.04	0.06	102	19
700	1000	<10	0.04	0.04	112	19
550	1000	<10	0.05	0.06	<100	17
550	600	<10	0.03	0.03	119	17
400	500	<10	0.03	0.05	<100	17
550	600	<10	0.03	0.05	<100	19
400	800	<10	0.06	0.09	<100	19
500	3000	<10	0.06	0.09	102	21
600	1000	<10	0.06	0.07	<100	19
400	800	<10	0.06	0.10	<100	14
400	800	<10	0.06	0.07	<100	14
400	1200	<10	0.06	0.07	<100	14
500	1000	<10	0.06	0.07	<100	14
300	800	<10	0.06	0.09	<100	14
			Roof and side walls			
150	300	<10	<0.03	<0.03	<100	
150	300	<10	<0.03	<0.03	170	
150	300	<10	<0.03	<0.03	<100	
150	300	<10	<0.03	<0.03	255	
150	300	<10	<0.03	<0.03	255	
150	300	<10	<0.03	<0.03	255	
150	300	<10	<0.03	<0.03	<100	
150	300	<10	<0.03	<0.03	102	
150	300	<10	<0.03	<0.03	102	

Table 11 (cont.). Alpha, beta and gamma radiation in Bunker E0811

Location	Direct alpha (dpm/100 cm^2)		Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] (mrad/hr)		Transferable beta (dpm/100 cm^2)
	average	maximum		average	maximum	
R10	150	300	<10	<0.03	<0.03	102
R11	150	300	<10	<0.03	<0.03	<100
R12	150	300	<10	<0.03	<0.03	<100
R13	150	300	<10	<0.03	<0.03	<100
R14	150	300	<10	<0.03	<0.03	<100
R15	150	300	<10	<0.03	<0.03	102
R16	150	300	<10	<0.03	<0.03	<100
				End walls		
E 1	200	500		<0.03	<0.03	102
E 2	200	500		<0.03	<0.03	<100
E 3	150	300		<0.03	<0.03	<100
E 4	150	300		<0.03	<0.03	102

[a]Includes gamma rays.

Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External gam at 1 m (μR/hr)
			Floor			
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
<100	<100	<10	<0.03	<0.03	<100	10
			Roof and side walls			
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	
<100	<100	<10	<0.03	<0.03	<100	

Table 12 (cont.). Alpha, beta, and gamma radiation in Bunker C0912

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)
R13	<100	<100	<10	<0.03	<0.03	<100
R14	<100	<100	<10	<0.03	<0.03	<100
R15	<100	<100	<10	<0.03	<0.03	<100
R16	<100	<100	<10	<0.03	<0.03	<100
			End walls			
E1	<100	<100	<10	<0.03	<0.03	<100
E2	<100	<100	<10	<0.03	<0.03	<100
E3	<100	<100	<10	<0.03	<0.03	<100
E4	<100	<100	<10	<0.03	<0.03	<100

[a] Includes gamma rays.

Table [illegible]. Concentrations of ^{222}Rn
measured in bunkers

Bunker Number	Location inside bunker	^{222}Rn (pCi/liter)
C0912	Rear	0.5
C0912	Front	1.8
E0801	Rear	1.0
E0801	Front	1.8
E0802	Rear	1.5
E0802	Front	1.0
E0803	Rear	1.4
E0803	Front	1.6
E0804	Rear	5.5
E0804	Front	2.6
E0805	Rear	3.2
E0805	Front	3.9
E0806	Rear	3.9
E0806	Front	5.8
E0807	Rear	2.5
E0807	Front	3.2
E0808	Rear	5.3
E0808	Front	5.9
E0809	Rear	6.4
E0809	Front	6.1
E0810	Rear	4.2
E0810	Front	4.6
E0811	Rear	3.8
E0811	Front	2.4

C0912	0.013 WL
E0801	0.008 WL
E0802	0.007 WL
E0803	0.009 WL
E0804	0.041 WL
E0805	0.046 WL
E0806	0.047 WL
E0807[b]	0.027 WL
E0807[b]	0.046 WL
E0808	0.048 WL
E0809	0.037 WL
E0810	0.016 WL
E0811[c]	0.018 WL
E0811[c]	0.010 WL
E0811[c]	0.017 WL

[a] A working level (WL) is defined as any combination of short-lived radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.

[b] Two measurements were taken in this bunker.

[c] Three measurements were taken in this bunker

in soil samples

Sample number	Depth (in.)	^{226}Ra (pCi/g)
SA1	0-6	1.0
SA2	0-10	0.9
SA3	0-12	0.7
SA4	20	1.0
SA4A	0-6	7820
SA4B	6-16	260
SA4C	0-12	4.6
SA5	Surface	288
SA5A	12	15.2
SA5B	0-12	31.1
SA6	0-6	16.0
SA7	0-6	48.2
SA7A	6-10	29.9
SA8	0-6	215
SA8A	6-10	71.2
SA9	0-6	15.4
SA10	0-6	275
SA10B	0-6	1.1
SA11	3-6 [a]	210
SA11A	Surface [b]	2330
SA11B	0-4	4.6
SE0804	Surface [c]	46,300
SA912	Surface	0.8

[a] Taken from under asphalt.
[b] Asphalt sample.
[c] Taken from a drain trough inside Bunker E0804.

in selected soil samples

Sample number	Depth (in.)	^{238}U (pCi/g)	^{232}Th (pCi/g)	^{40}K (pCi/
SA1	0-6	2.0	0.9	19.
SA2	0-10	1.7	1.0	20.
SA3	0-12	0.7	0.9	21.
SA5A	12	11.8	0.5	11.
SA5B	0-12	25.8	1.3	19.
SA6	0-6	8.5	1.2	17.
SA7A	6-10	8.9	1.0	20.
SA8	0-6	60.1	N.F.[a]	N.
SA9	0-6	8.6	N.F.	8.
SA10B	0-6	2.1	1.1	21.
SE0804	Surface[b]	67,070	N.F.	N.
SA912	Surface	1.6	0.8	13.

[a]N.F. = not found.

[b]Taken from a drain trough inside Bunker E0804.

^{226}Ra	^{227}Th	^{230}Th	^{232}Th	^{234}U	^{235}U	^{238}U
1×10^{-4}	2.3×10^{-4}	$\leq4.5\times10^{-5}$	$<4.5\times10^{-5}$	5.9×10^{-4}	1.4×10^{-4}	$4.5\times10^{-}$
9×10^{-4}	1.6×10^{-4}	$\leq4.5\times10^{-5}$	$<4.5\times10^{-5}$	$1\ \times10^{-3}$	$\leq1.8\times10^{-4}$	$8.1\times10^{-}$
$\times10^{-2}$	7	2	2	30	30	40

Bunker	Maximum reading (in dpm/100 cm^2)
E0801	400
E0802	700
E0803	500
E0804	1000
E0805	500
E0806	1000
E0807	400
E0808	400
E0809	600
E0810	600
E0811	400
A0804	700
A0810	700

DESCRIPTION OF RADIATION SURVEY

METERS AND SMEAR COUNTERS

Alpha Survey Meters

Two types of alpha survey meters are used to measure alpha radioactivity on surfaces. One type of instrument uses a ZnS scintillator and the other uses a gas-flow proportional counter to detect the alpha radiation.

The alpha scintillation survey meter consists of a large area (100 cm^2) ZnS detector with a photomultiplier tube in the probe which is coupled to a portable scaler/ratemeter (see Fig. I-A). The ZnS detector is covered with a 5-mil aluminized mylar sheet in order to make the instrument light-tight. The mylar, in turn, is covered with a grid to prevent puncturing the detector when surveying over rough surfaces. This instrument is capable of measuring alpha surface contamination levels of a few dpm/100 cm^2 but must be used in the scaler mode for this purpose. It is highly selective for densely ionizing radiation such as alpha particles; the instrument is relatively insensitive to beta and gamma radiation.

The gas-flow proportional counter uses propane gas as the detection medium. Through front panel meter readings, it can be used to measure alpha contamination levels from a few hundred dpm/100 cm^2 to several hundred thousand dpm/100 cm^2. If individual pulses are counted, this instrument can also be used for measurements down to a few dpm/100 cm^2. The probe has a surface area of approximately 61 cm^2 and has a 2.5-mil

PAC-4G meter with a probe.

Both of these instruments are calibrated at ORNL using ^{239}Pu alph
sources. While each instrument is individually calibrated, the cali-
bration factors are typically 5-6 dpm/cpm.

Beta Survey Meter

A portable Geiger-Mueller (G-M) survey meter is the primary instr
ment for measuring beta-gamma radioactivity. The G-M tube is a haloge
quenched stainless steel tube having a 30 mg/cm^2 wall thickness and
presenting a cross-sectional area of approximately 10 cm^2. Since the
tube is sensitive to both beta and gamma radiation, measurements are
taken in both an open window and a closed-window configuration. Beta
radiation cannot penetrate the closed window, and, thus, the beta
reading can be determined by taking the difference between the open ar
closed window readings. This meter is shown in Fig. I-C.

The G-M survey meter was calibrated at ORNL for gamma radiation
using an NBS standard Ra source. The gamma calibration factor is typi
of the order of 2600 cpm per mR/hr.

In order to assess beta-gamma surface dose rates from uranium con
taminated surfaces using this instrument, a field calibration was per-
formed. The G-M survey meter was compared with a Victoreen Model 440
ionization chamber (see Fig. I-D) and was found to produce 1750 cpm pe

A portable survey meter using a NaI scintillation probe is used measure low-level gamma radiation exposure. The scintillation probe a 3.2 x 3.8-cm NaI crystal coupled to a photomultiplier tube. This probe is connected to a Victoreen Model Thyac III ratemeter (see Fig. This unit is capable of measuring radiation levels from a few μR/hr to several hundred μR/hr. This instrument is calibrated at ORNL with NBS standard ^{226}Ra source. Typical calibration factors are of the or of 300 cpm per μR/hr.

SMEAR COUNTERS

Alpha Smear Counter

This detector assembly, used for the assay of alpha emitters on smear paper samples, consists of a light-tight sample holder, a zinc sulfide phosphor and a photomultiplier tube. The detector assembly i used with N/M modular electronic components. The electronics package consisted of a preamplifier, an ORTEC 456 high voltage power supply, Tennelec TC 211 linear amplifier and a Tennelec TC 545 counter-timer. alpha smear counter used in the field is calibrated daily using an al source with a known disintegration rate.

Beta Smear Counter

The beta smear counter consists of a thin mica window (∿ 2 mg/cm G-M tube mounted on a sample holder and housed in a 23-cm diam x 35-c

counting rate. The electronics for this counter is housed in a port
NIM bin and consists of a Tennelec TC 148 preamplifier, an ORTEC 456
high voltage power supply and a Tennelec TC 545 counter-timer. This
is used in the field to measure beta activity on smear papers and wa
calibrated daily using a beta standard of known activity. The instr
used for measuring alpha and beta activity on smear papers are shown
Fig. I-F.

The mobile laboratories shown in Fig. I-G are used during each
survey to serve as a control center, and to house instruments and ot
equipment needed during the survey. Each lab is equipped with its o
electric generator, mobile radio-telephone, and contains a wide rang
well maintained and calibrated instruments. One of the mobile labs
its own microcomputer for data reduction in remote locations.

ORNL Photo 6705-

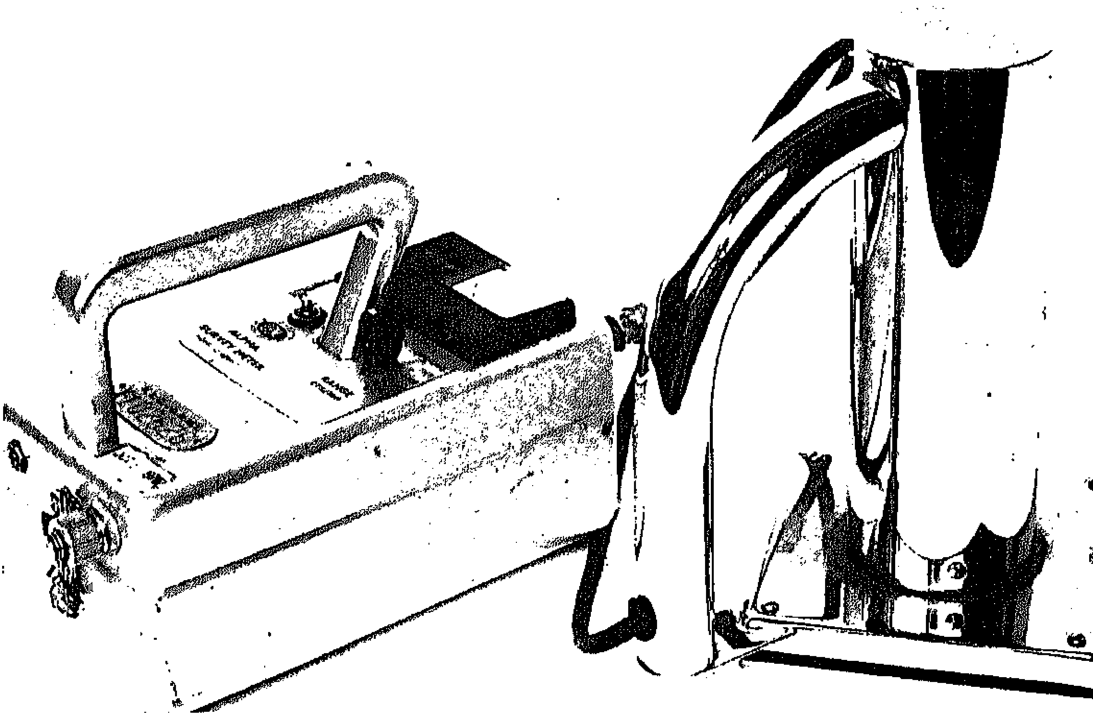

Fig. I-A. Alpha scintillation survey meter.

ORNL Photo 6?

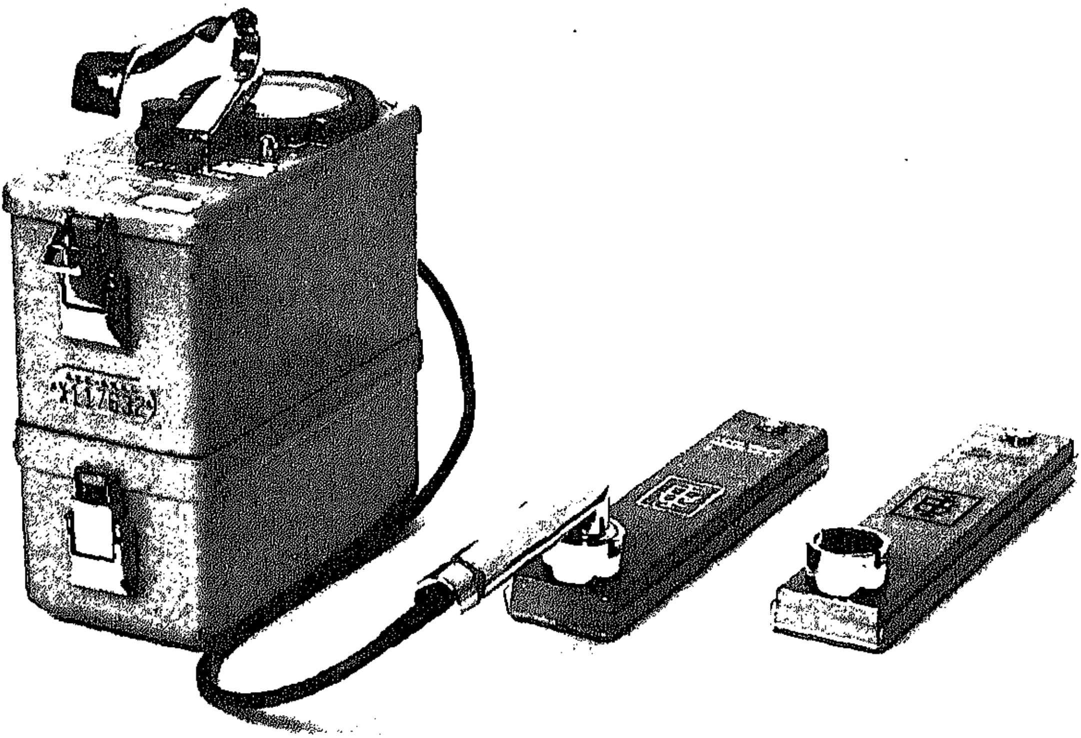

Fig. I-B. Gas-flow proportional alpha survey meter.

ORNL Photo 670

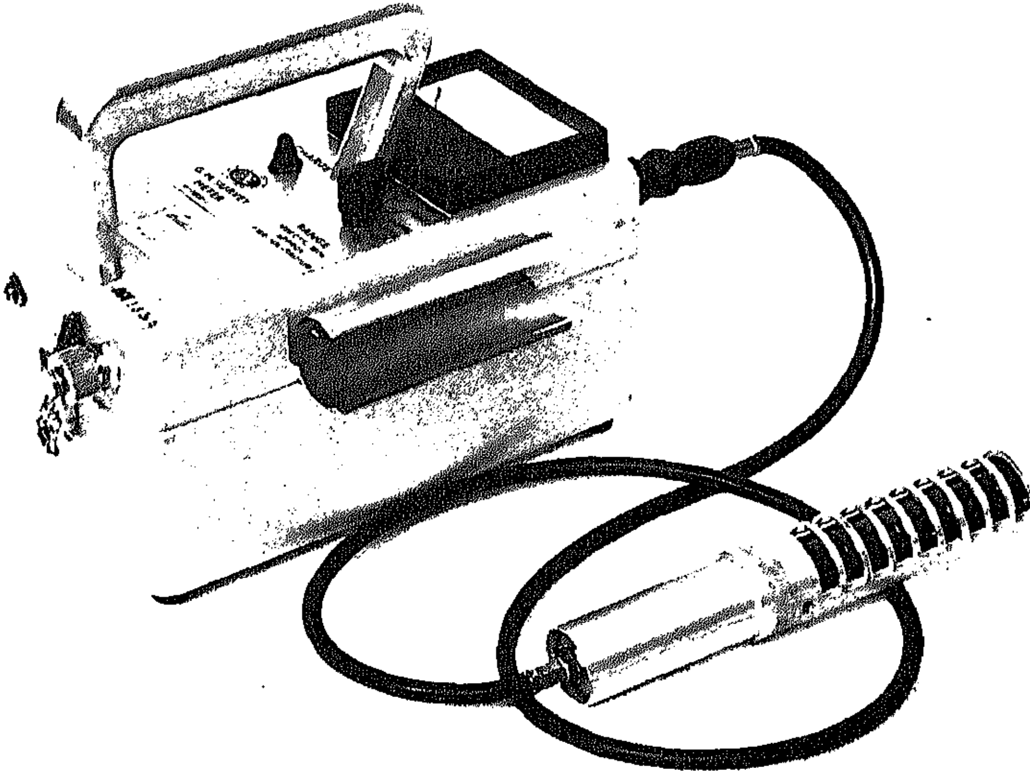

Fig. I-C. Geiger-Mueller survey meter.

ORNL Photo 6710-76

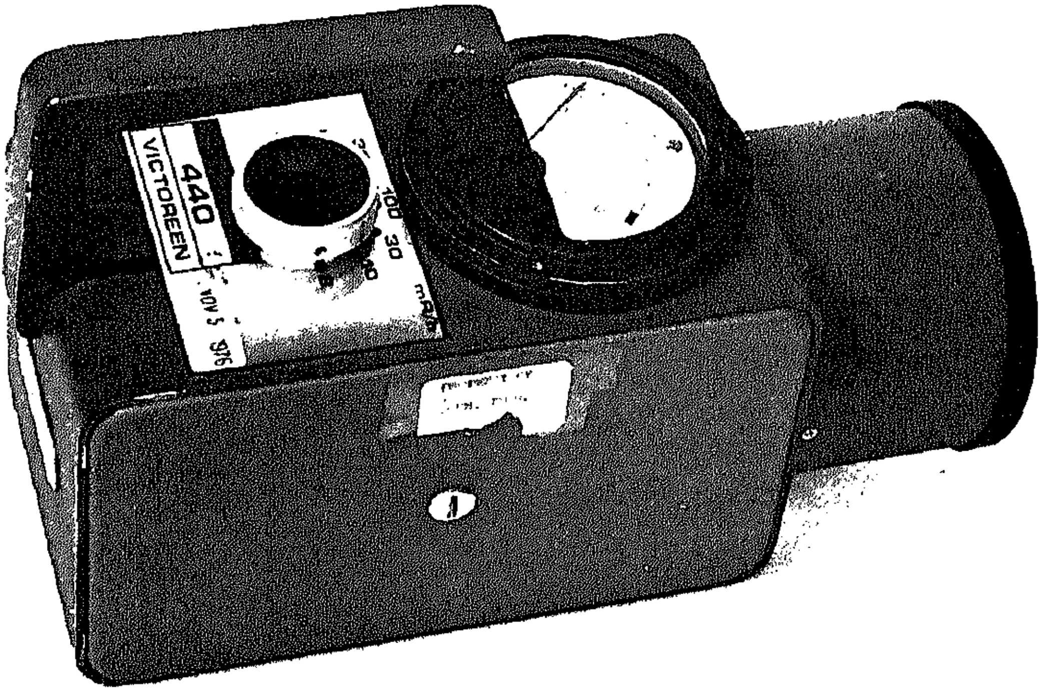

Fig. I-D. Victoreen Model 440 ionization chamber

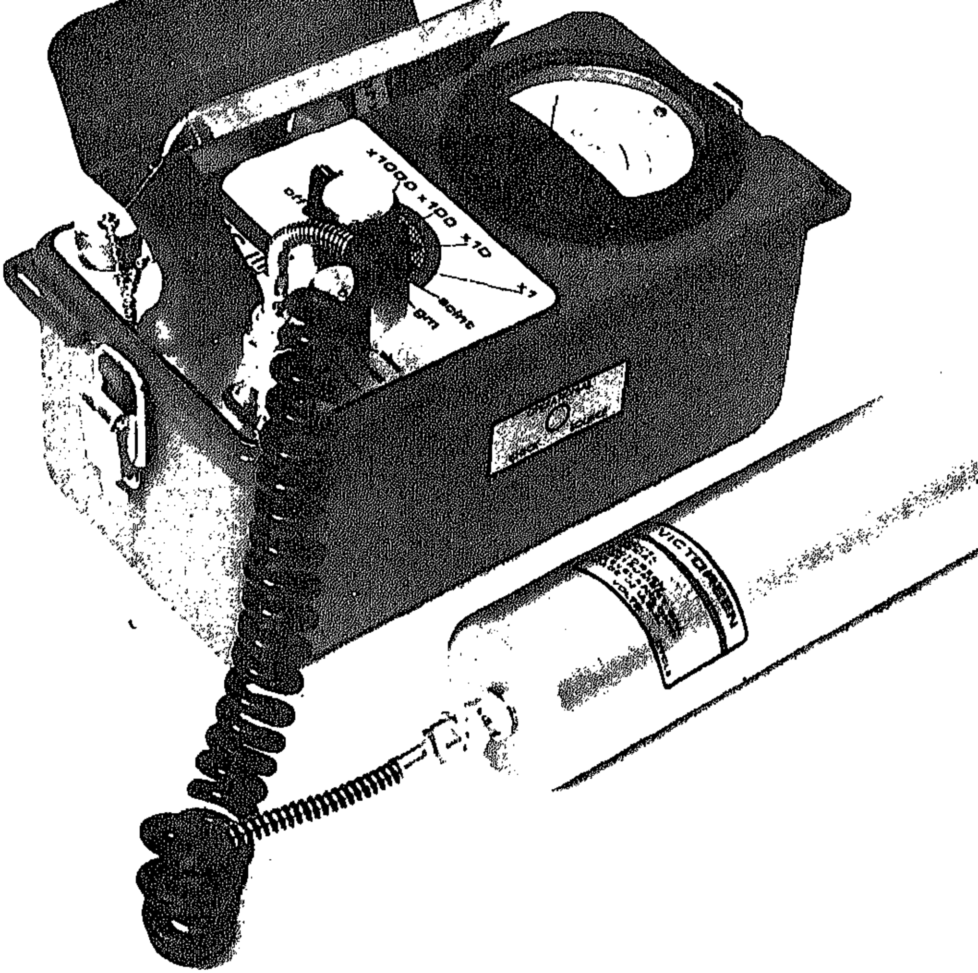

Fig. I-E. Gamma scintillation survey meter.

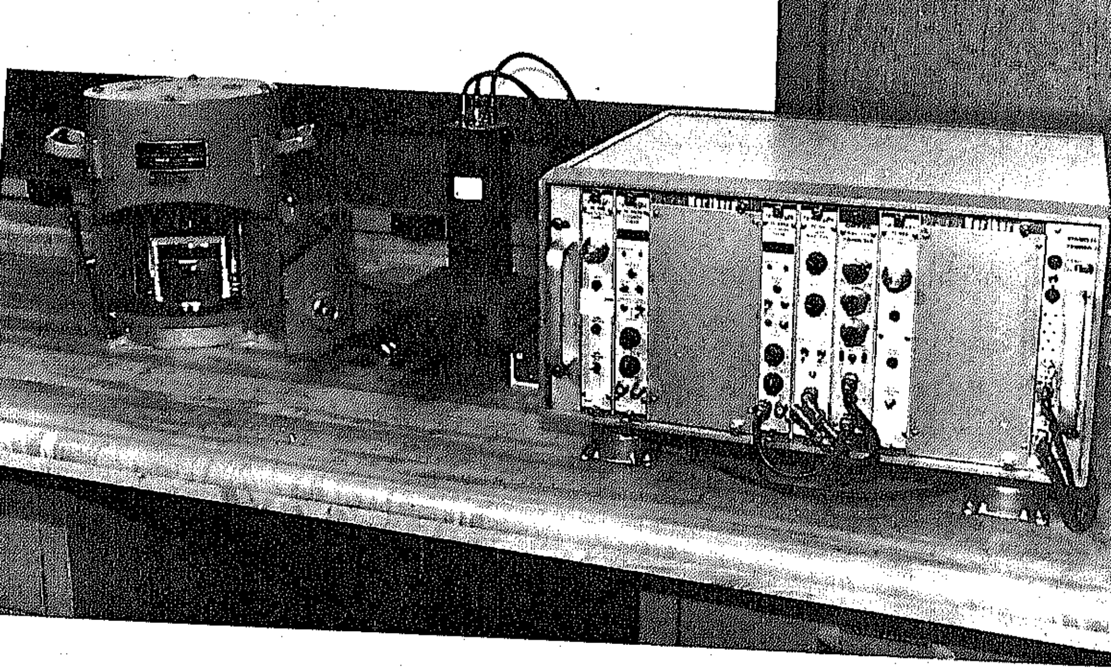

Fig. I-F. Smear counter and associated electronics. The beta counter is on the left and the alpha counter is on the right.

ORNL Photo 1068

Fig. I-G. Mobile labs used for logistic support during surveys.

DESCRIPTION OF THE TECHNIQUES FOR THE MEASUREMENT OF RADON AND RADON DAUGHTER CONCENTRATIONS IN AIR

An alpha spectrometry technique has been refined by Kerr[1,2] fo the measurement of ^{222}Rn progeny concentrations in air. From one i count of the ^{218}Po alpha activity and two integral counts of the ^{21} alpha activity, the concentrations in air of ^{218}Po, ^{214}Bi and ^{214}Pb be calculated.

Particulate ^{222}Rn daughters attached to airborne dust are coll on a membrane filter with a pore size of 0.4 μ. A sampling time of 5 min and a flow rate of 12 LPM are used. This filter sample is then placed under a silicon surface barrier detector and counted. detector and counting system used for radon daughter measurements a shown in Fig. II-A. Usually, counting of this kind is performed wi vacuum between the sample and the detector which requires a complic sample holder and time-consuming sample changing methods. Experime this laboratory have shown that ease in sample handling is obtained with little loss in resolution when helium is used as a chamber fil gas.[3] In this counter, helium is flowed between the diode and the filter sample, which are separated by a distance of 0.5 cm. One in count of the ^{218}Po alpha activity is obtained from 2 to 12 min, and two integral counts of the ^{214}Po activity are obtained from 2 to 12 min and 15 to 30 min, respectively. All counting intervals are referenced to t = 0 at the end of sampling.

The equations describing the ^{222}Rn progeny atoms collection ra

C_i = concentration of the i^{th} species (atoms liter^{-1}), and

v = air sampling flow rate (liters min^{-1}).

The solution of Eq. (1) is of the form

$$y = e^{-ax} [y_0 = \int F(x)\ e^{ax} dx].$$

From the general form of the solution, specific equations ca[n be obtained] describing the number of each ^{222}Rn decay product collected on th[e filter] as a function of time. Also by letting v = 0 in Eq. (1), a set o[f equations] describing the decay on the filter of each ^{222}Rn progeny can be ob[tained]. The equations describing the decay of ^{222}Rn progeny on the filter [are] integrated and related to the integral counts obtained experimenta[lly]. Values for the total activities of ^{218}Po, ^{214}Pb, and ^{214}Bi on the [filter] at the end of sampling are obtained by applying matrix techniques. [The] airborne concentrations are obtained by solving the equations descr[ibing] the atom collection rates on the filter. A computer program has be[en] written to perform these matrix operations, to calculate the air co[n]centrations of the radon progeny, and to estimate the accuracy of t[he] calculated concentrations.

Technique for the Measurement of Radon Concentrations in the Air

A Lucas Chamber (Fig. II-B) consists of a 95-ml glass flask, co inside with a uniform layer of zinc sulfide. For measurements of ra concentration in the air, the flask is evacuated to a pressure of 50 The flask is then taken to a location where a sample is desired and the collection valve is opened. After collection of air in the sample counting is delayed 3 to 4 hr to allow the radon daughters to attain equilibrium. Alpha particles from the radon daughters produc scintillations in the zinc sulfide. The sample is normally counted 1000 sec with a photomultiplier tube assembly. A calibration perfor at ORNL using a known radon concentration indicated that the convers factor is 2.02 pCi/liter per cpm. After the sample has been counted the flask is again evacuated to 50 μ to prevent contamination.

II-1. G. D. Kerr, *Measurement of Radon Progeny Concentrations in Air by Alpha-Particle Spectrometry*, ORNL/TM-4924 (July 1975).

II-2. G. D. Kerr, "Measurement of Radon Progeny Concentrations in Air," *Trans. Am. Nuc. Soc.* 17, 541 (1973).

II-3. P. T. Perdue, W. H. Shinpaugh, J. H. Thorngate and J. A. Auxier, "A Convenient Counter for Measuring Alpha Activity of Smear and Air Samples," *Health Phys.* 26, 114 (1974).

ORNL Photo 1077

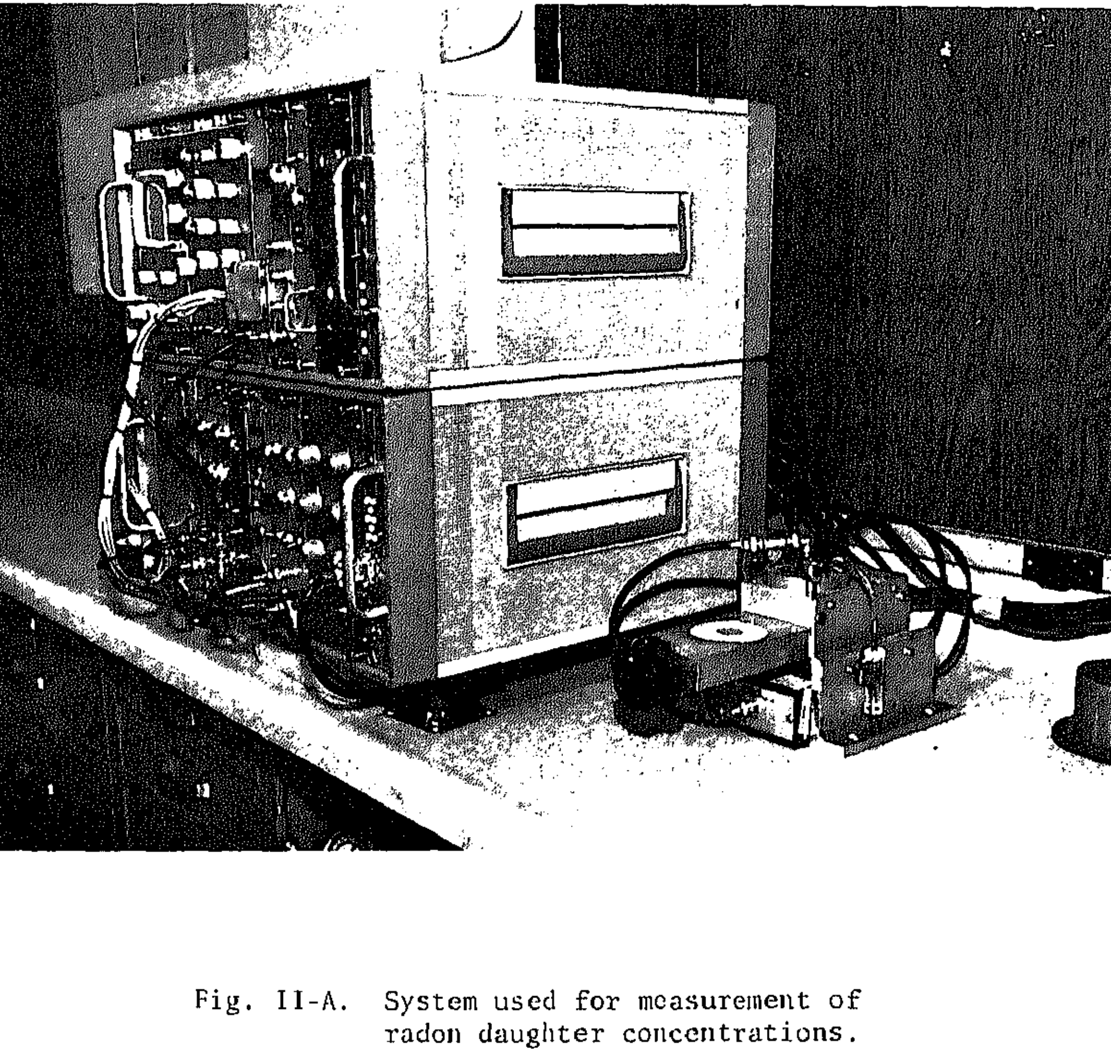

Fig. II-A. System used for measurement of radon daughter concentrations.

ORNL Photo 1083-7

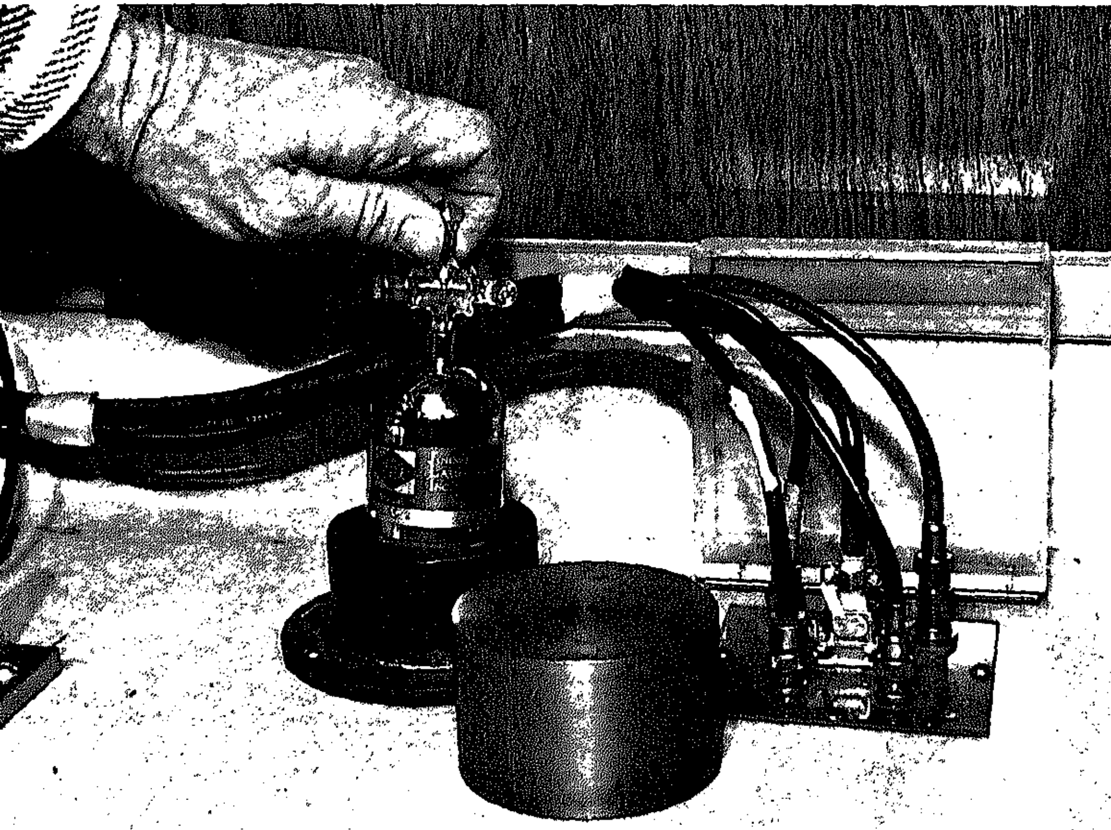

Fig. II-B. Lucas Chamber.

DESCRIPTION OF GeLi DETECTOR AND

SOIL COUNTING PROCEDURES

A holder for twelve 30-cc polyethylene bottles (standard contain for liquid scintillation samples) and a background shield have been designed for use with a 50-cc Ge(Li) detector system in laboratory counting of radioactivity in environmental samples (see Fig. III-A). During counting of the samples, the holder is used to position ten of the sample bottles around the cylindrical surface of the detector, parallel to and symmetric about its axis, and two additional bottles across the end surface of the detector, perpendicular to and symmetri with its axis. With a 300-cc sample and a graded shield developed fo use with the system, it is possible to measure 1 pCi/g of ^{232}Th or ^{22} with an error of ± 10% or less.

Pulses are sorted by a 4096-channel computer based analyzer (see Fig. III-B), stored on magnetic tape, and subsequently entered into a computer program which uses an iterative least squares method to iden radionuclides corresponding to those gamma-ray lines found in the sam The program relies on a library of radioisotopes which contains appro mately 700 isotopes and 2500 gamma-rays and which runs continuously o the IBM-360 system at ORNL. In identifying and quantifying ^{226}Ra, six principal gamma-ray lines are analyzed. Most of these are from ^{214}Bi and correspond to 295, 352, 609, 1120, 1765, and 2204 KeV. An estima of the concentration of ^{238}U is obtained from an analysis of the 93 K line from its daughter ^{234}Th.

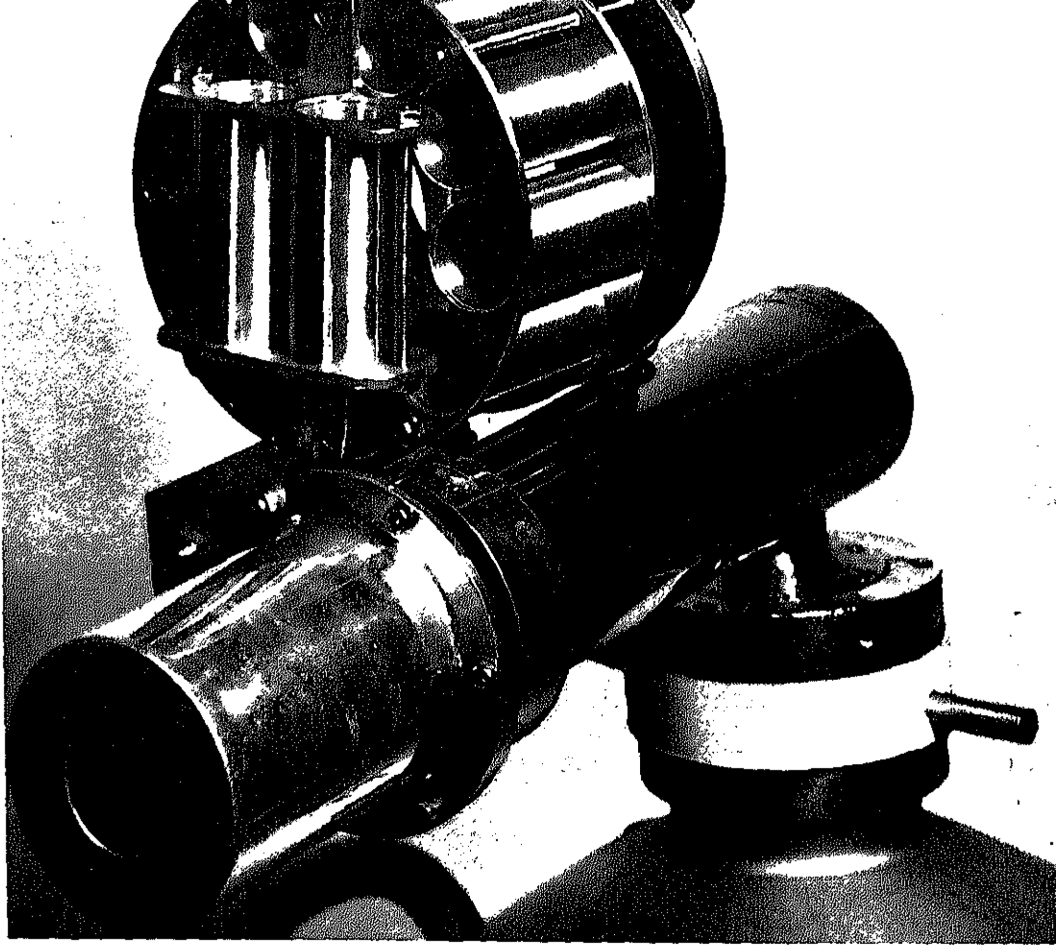

Fig. III-A. Holder for Ge(Li) detector system samples.

ORNL Photo 6719-76

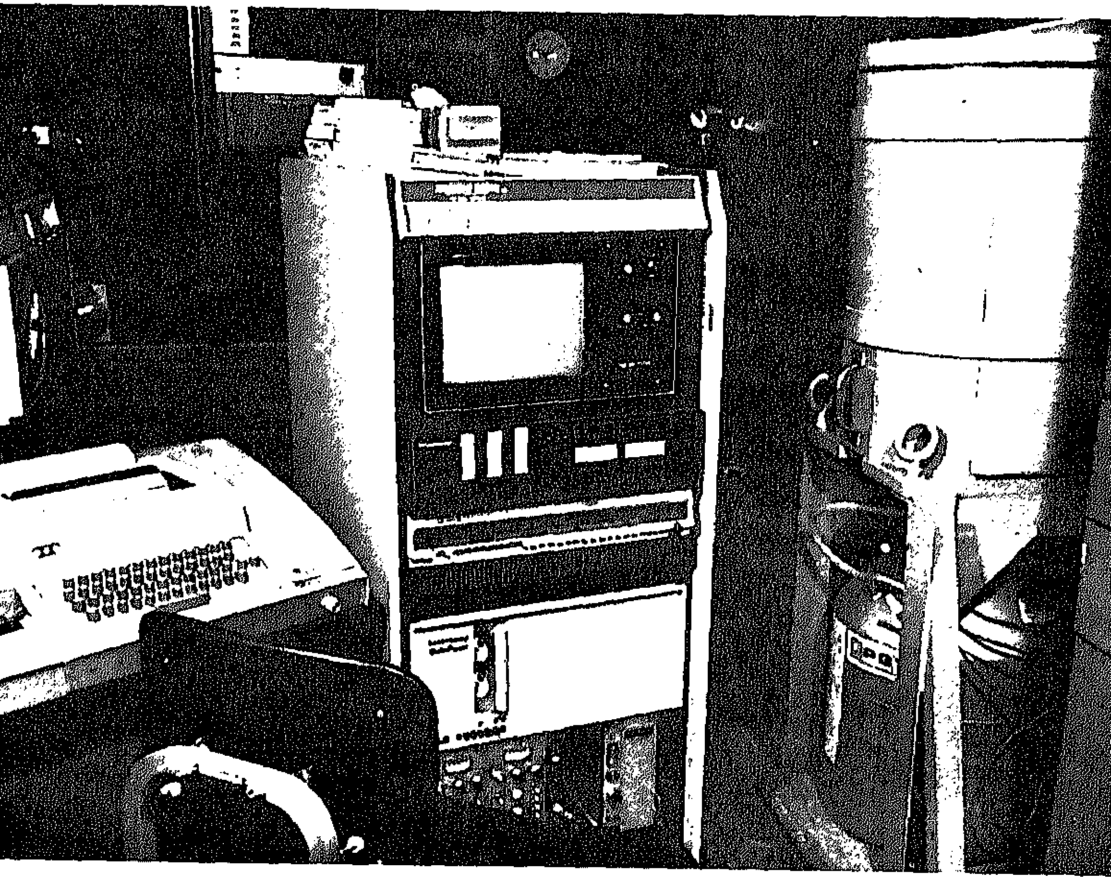

Fig. III-B. Computer-based 4096 channel analyzer.

GRAND JUNCTION REMEDIAL ACTION CRITERIA, 10 CFR 712

AND

NRC GUIDELINES FOR SURFACE CONTAMINATION LIMITS

PRIOR TO RELEASE FOR UNRESTRICTED USE

OR TERMINATION OF LICENSES FOR BYPRODUCT, SOURCE,

OR SPECIAL NUCLEAR MATERIAL

U. S. Nuclear Regulatory Commission
Division of Fuel Cycle
and Material Safety
Washington, D. C. 20555

November 1976

and equipment prior to abandonment or release for unrestricted u
The limits in Table IV-1 do not apply to premises, equipment, or
containing induced radioactivity for which the radiological cons
tions pertinent to their use may be different. The release of s
facilities or items from regulatory control will be considered o
case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate re contamination.

2. Radioactivity on equipment or surfaces shall not be covered paint, plating, or other covering material unless contamina levels, as determined by a survey and documented, are below limits specified in Table IV-1 prior to applying the coveri reasonable effort must be made to minimize the contaminatio prior to use of any covering.

3. The radioactivity on the interior surfaces of pipes, drain or ductwork shall be determined by making measurements at a and other appropriate access points, provided that contamin at these locations is likely to be representative of contam on the interior of the pipes, drain lines, or ductwork. Su of premises, equipment, or scrap which are likely to be con but are of such size, construction, or location as to make surface inaccessible for purposes of measurement shall be p to be contaminated in excess of the limits.

4. Upon request, the Commission may authorize a licensee to re possession or control of premises, equipment, or scrap havi contaminated with materials in excess of the limits specifi may include, but would not be limited to, special circumsta as razing of buildings, transfer or premises to another org continuing work with radioactive materials, or conversion o to a long-term storage or standby status. Such request mus

   a. Provide detailed, specific information describing premises, equipment or scrap, radioactive contami and the nature, extent, and degree of residual su contamination.

   b. Provide a detailed health and safety analysis whi that the residual amounts of materials on surface together with other considerations such as prospe of the premises, equipment or scrap, are unlikely result in an unreasonable risk to the health and

contamination is within the limits specified in Table IV-1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

a. Identify the premises.

b. Show that reasonable effort has been made to eliminate residual contamination.

c. Describe the scope of the survey and general procedures followed.

d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDES[a]	AVERAGE[b c f]	MAXIMUM[b d f]	
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,0
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	
Th-nat, Th-232, Sr-90 Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm^2	3,000 dpm/100 cm^2	20
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except SR-90 and other noted above.	5,000 dpm $\beta\gamma$/100 cm^2	15,000 dpm $\beta\gamma$/100 cm^2	1,00

[a]Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits establishe
beta-gamma-emitting nuclides should apply independently.

[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive materia
by correcting the counts per minute observed by an appropriate detector for background, efficiency, and ge
associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of
area, the average should be derived for each such object.

[d]The maximum contamination level applies to an area of not more than 100 cm^2.

[e]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping th
dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive ma
wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less
is determined, the pertinent levels should be reduced proportionally and the entire surface should be wipe

[f]The average and maximum radiation levels associated with surface contamination resulting from beta-gamma e
not exceed 0.2 mrad/hr at 1 cm and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 mil
square centimeter of total absorber.

Propos

ANSI N

Proposed American National Standard

Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use

Secretariat

Health Physics Society

(e.g., some pipes, drains, and ductwork), such property shall not be released pursuant to this standard, but made the subject of case-by-case evaluation. Credit shall not be taken for coatings over contamination.

SURFACE CONTAMINATION LIMITS

The levels may be averaged* over the 1 m^2 provided the maximum

in any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit dpm Total
Group 1: Nuclides for which the nonoccupational MPC_a† is 2×10^{-13} Ci/m^3 or less or for which the nonoccupational MPC_w‡ is 2×10^{-7} Ci/m^3 or less; includes Ac-227; Am-241; -242m, -243; Cf-249; -250, -251, -252; Cm-243, -244, -245, -246, -247, -248; I-125, -129; Np-237; Pa-231; Pb-210; Pu-238, -239 -240, -242, -244; Ra-226, -228; Th-228, -230.§	100
Group 2: Those nuclides not in Group 1 for which the nonoccupational MPC_a† is 1×10^{-12} Ci/m^3 or less or for which the nonoccupational MPC_w‡ is 1×10^{-6} Ci/m^3 or less; includes Es-254; Fm-256; I-126, -131, -133; Po-210; Ra-223; Sr-90; Th-232; U-232.§	1,000
Group 3: Those nuclides not in Group 1 or Group 2.	5,000

*See note following Table 2 on application of limits.

†MPC_a: Maximum Permissible Concentration in Air applicable to exposure of members of the public as published by or derived f authoritative source such as NCRP, ICRP or NRC (10 CFR Part 20 Table 2, Column 1).

‡MPC_w: Maximum Permissible Concentration in Water applicable bers of the public.

§Values presented here are obtained from 10 CFR Part 20. The limiting of all given MPC values (e.g. soluble vs. insoluble)

(All alpha emitters, except U-nat and Th-nat are considered as a g

The levels may be averaged over 1 m^2* provided the maximum activit

any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit (Acti dpm/100 Total
If the contaminant cannot be identified; or if alpha emitters other than U-nat and Th-nat are present; or if the beta emitters comprise Ac-227, Ra-226, Ra-228, I-125 and I-129.	100
If it is known that all alpha emitters are generated from U-nat and Th-nat; and beta emitters are present which, while not identified, do not include Ac-227, I-125, I-129, Ra-226 and Ra-228.	1,000
If it is known that alpha emitters are generated only from U-nat and Th-nat; and the beta emitters, while not identified, do not include Ac-227, I-125, I-129, Sr-90, Ra-223, Ra-228, I-126, I-131 and I-133.	5,000

*NOTE ON APPLICATION OF TABLES 1 AND 2 TO ISOLATED SPOTS OR ACTIVI

For purposes of averaging, any m^2 of surface shall be considered contaminated above the limit, L, applicable to 100 cm^2 if:

a. From measurements of a representative number, n, of sections, determined that $1/n \sum_n Si > L$, where Si is the dpm/100 cm^2 determin measurement of section i; or

b. On surfaces less than 1 m^2, it is determined that $1/n \sum_n Si \geq$ where A is the area of the surface in units of m^2; or

c. It is determined that the activity of all isolated spots or p in any area less than 100 cm^2 exceeds 3L.

Grand Junction Remedial Action Criteria

Federal Register, Vol. 41, No. 253, pp. 56777-8, Thursday, December 30

PART 712 - GRAND JUNCTION
REMEDIAL ACTION CRITERIA

712. 1 Purpose

(a) The regulations in this part establish the criteria for deter-mination by ERDA of the need for, priority of and selection of appropr remedial action to limit the exposure of individuals in the area of Grand Junction, Colo., to radiation emanating from uranium mill tailin which have been used as construction-related material.

(b) The regulations in this part are issued pursuant to Publ. L. 92-314 (86 Stat. 222) of June 16, 1972.

713.2 Scope

The regulations in this part apply to all structures in the area Grand Junction, Colo., under or adjacent to which uranium mill tailing have been used as a construction-related material between January 1, 1 and June 16, 1972, inclusive.

712.3 Definitions

As used in this part:

(a) "Administrator" means the Administrator of Energy Research a

(d) "ERDA" means the U.S. Energy Research and Development Admin-
ration or any duly authorized representative thereof.

(e) "Construction-related material" means any material used in the
struction of a structure.

(f) "External gamma radiation level" means the average gamma
iation exposure rate for the habitable area of a structure as measured
r floor level.

(g) "Indoor radon daughter concentration level" means that concen-
tion of radon daughters determined by: (1) Averaging the results of
ir samples, each of at least 100 hours duration, and taken at a minimu
4-week intervals throughout the year in a habitable area of a structu
(2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen (mR) means a unit equal to one-thousandth (1/10
a roentgen which roentgen is defined as an exposure dose of X or gamma
iation such that the associated corpuscular emission per 0.001293 gra
air produces, in air, ions carrying one electrostatic unit of quantity
electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the
ticulate radiation (alpha and beta) which emanate from the radioactive
ay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of rado
. Generally, these include Radium A (polonium-218), Radium B (lead-2

pectation of reducing the radiation exposure resulting from uranium tailings which have been used as construction-related material in an around structures in the area of Grand Junction, Colo.

(l) "Surgeon General's guidelines" means radiation guidelines lated to uranium mill tailings prepared and released by the Office o the U.S. Surgeon General, Department of Health, Education and Welfar July 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium mill tion involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

712.4 Interpretations

Except as specifically authorized by the Administrator in writi interpretation of the meaning of the regulations in this part by an or employee of ERDA other than a written interpretation by the Gener Counsel will be recognized to be binding upon ERDA.

712.5 Communications

Except where otherwise specified in this part, all communicatio concerning the regulations in this part should be addressed to the D Division of Safety, Standards, and Compliance, U.S. Energy Research Development Administration, Washington, D.C. 20545.

(d) "ERDA" means the U.S. Energy Research and Development Administration or any duly authorized representative thereof.

(e) "Construction-related material" means any material used in construction of a structure.

(f) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) Averaging the results of 6 air samples, each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen (mR) means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-214),

ectation of reducing the radiation exposure resulting from uranium mil ailings which have been used as construction-related material in and round structures in the area of Grand Junction, Colo.

(l) "Surgeon General's guidelines" means radiation guidelines reated to uranium mill tailings prepared and released by the Office of he U.S. Surgeon General, Department of Health, Education and Welfare o uly 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium mill op ion involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived rad aughter products in 1 liter of air that will result in the ultimate mission of 1.3×10^5 MeV of potential alpha energy.

12.4 Interpretations

Except as specifically authorized by the Administrator in writing, nterpretation of the meaning of the regulations in this part by an off r employee of ERDA other than a written interpretation by the General ounsel will be recognized to be binding upon ERDA.

12.5 Communications

Except where otherwise specified in this part, all communications oncerning the regulations in this part should be addressed to the Dire ivision of Safety, Standards, and Compliance, U.S. Energy Research and evelopment Administration, Washington, D.C. 20545.

action in terms of external gamma radiation level (EGR) and indoor
daughter concentration level (RDC) above background found within d
constructed on or with uranium mill tailings:

EGR	RDC	Recommenda
Greater than 0.1 mR/hr.	Greater than 0.05 WL.	Remedial action
From 0.05 to 0.1 mR/hr.	From 0.01 to 0.05 WL.	Remedial action suggested.
Less than 0.05 mR/hr.	Less than 0.01 WL.	No remedial acti dicated.

712.7 Criteria for determination of possible need for remedial

Once it is determined that a possible need for remedial actio
the record owner of a structure shall be notified of that structur
eligibility for an engineering assessment to confirm the need for
action and to ascertain the most appropriate remedial measure, if
determination of possible need will be made if as a result of the
of uranium mill tailings under or adjacent to the structure, one c
following criteria is met:

(a) Where ERDA approved data on indoor radon daughter concen
levels are available:

(1) For dwellings and schoolrooms: An indoor radon daughter

level of 0.03 WL or greater above background.

(b) Where ERDA approved data on indoor radon daughter concentra

levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/hr. or greater

background.

(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(A) It may be presumed that if the external gamma radiation lev is equal to or exceeds 0.02 mR/hr. above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above backgrou

(B) It should be presumed that if the external gamma radiation is less than 0.001 mR/hr. above background, the indoor radon daughter concentration level is less than 0.01 WL above background and no poss need for remedial action exists.

(C) If the external gamma radiation level is equal to or greate than 0.001 mR/hr. above background but is less than 0.02 mR/hr. above background, measurements will be required to ascertain the indoor rad daughter concentration level.

(2) For other structures: (i) An external gamma radiation leve 0.15 mR/hr. above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiati

The possible need for remedial action may be determined where criteria in 712.7 have not been met if various other factors are p Such factors include, but are not necessarily limited to, size of affected area, distribution of radiation levels in the affected ar amount of tailings, age of individuals occupying affected area, oc time, and use of the affected area.

712.9 Factors to be considered in determination of order or pr for remedial action

In determining the order or priority for execution of remedia consideration shall be given, but not necessarily limited to, the factors:

(a) Classification of structure. Dwellings and schools shal considered first.

(b) Availability of data. Those structures for which data c radon daughter concentration levels and/or external gamma radiatio are available when the program starts and which meet the criteria 712.7 will be considered first.

(c) Order of application. Insofar as feasible remedial acti be taken in the order which the application is received.

(d) Magnitude of radiation level. In general, those structu the highest radiation levels will be given primary consideration.

located in the same immediate geographical vicinity may be given pr consideration particularly where they involve similar remedial effo

(f) Availability of structures. An attempt will be made to s remedial action during those periods when remedial action can be ta with minimum interference.

(g) Climatic conditions. Climatic conditions or other season considerations may affect the scheduling of certain remedial measur

712.10 *Selection of appropriate remedial action*

(a) Tailings will be removed from those structures where the propriately averaged external gamma radiation level is equal to or than 0.05 mR/hr. above background in the case of dwellings and scho and 0.15 mR/hr. above background in the case of other structures.

(b) Where the criterion in paragraph (a) of this section is n other remedial action techniques, including but not limited to seal ventilation, and shielding may be considered in addition to that of tailings removal. ERDA shall select the remedial action technique combination of techniques, which it determines to be the most appro under the circumstances.

Interim Primary Drinking Water Reguations
Promulgation of Regulations on Radionuclides
Federal Register, Vol. 41, No. 133, pp. 28402-9 Friday, July 9,

Part 141.15 Federal Register
Vol 41, No. 133, p 28404, Friday, July 9, 1976

Maximum contaminant levels for ^{226}Ra, ^{228}Ra, and gross alpha radioactivity.

(a) Combined ^{226}Ra and ^{228}Ra - 5 pCi/liter.

(b) Gross alpha particle activity (including ^{226}Ra but excl radon and uranium) - 15 pCi/liter.

EVALUATION OF RADIATION EXPOSURES

ROMULUS, NEW YORK

The U. S. Department of Energy has determined that the Seneca A
Depot in Romulus, New York, is presently contaminated with radioacti
residues resulting from previous uses of this property. The depot
covers approximately 10,000 acres and consists primarily of munition
bunkers. Eleven of these bunkers were used for the storage of appro
imately 2000 barrels of pitchblende ore during a short period in the
early 1940's. Upon removal of the ore, the bunkers reverted back to
storage sites for ammunition and have continued in this function sin
that time. These bunkers are occupied for only brief periods by Army
personnel, resulting in a total of approximately 20 to 30 man-hours o
occupancy per month.

Contamination at the Seneca site is due primarily to natural
uranium and radium-226. Employees at this site receive slight radiat
exposures from this contamination primarily because of infrequent occ
of contaminated bunkers. The principal means of exposures within the
bunkers is the inhalation of radon-222 and its short-lived daughters.
Additional exposures received by ingestion (e.g., eating or drinking
one of the bunkers) are relatively small compared with inhalation of
radon and daughters. A summary of radiation exposures at the Seneca
site is provided in Table V-1 along with appropriate guidelines and b
ground values.

ackground exposures. These background exposures are not caused by ny human activity and, to a large extent, can be controlled only thro in's moving to areas with lower background exposures. Each and every uman receives some background exposure daily.

The use of radioactive materials for scientific, industrial, or edical purposes may cause radiation exposures above the background le o be received by workers in the industry and, to a lesser extent, by embers of the general public. Scientifically based guidelines have een developed to place an upper limit on these additional exposures. imits established for exposures to the general public are much lower han the limits established for workers in the nuclear industry.

Uranium-238 is believed to have been created when the earth was ormed. It is still present today because it takes a very long time t ecay. The half-life is a measure of the time required for radioacti ecay; for uranium-238 it is 4.5 billion years. Thus, if 4.5 billion ears ago you had a curie[a] of uranium-238, today you would have one-ha urie; 4.5 billion years hence, this would only be one-fourth curie o ranium-238. As the uranium-238 decays, it changes into another subst horium-234. Thorium-234 is called the "daughter" of uranium-238. I horium-234 is the "parent" of protactinium-234. Radioactive decay st y uranium-238 continues as shown in Table V-2 until stable lead is ormed. The "decay product" listed in Table V-2 is the radiation pro

As may be seen in Table V-2, several of the daughters of urani and radium-226 emit gamma radiation (gamma-rays are penetrating radi like X-rays). Hence, the contaminated areas are sources of externa gamma radiation exposure.

External gamma exposure rates measured at one meter above the ground outside the bunkers ranged from 8 to 31 microRoentgens per ho Exposure rates inside the bunkers ranged from 10 to 21 microRoentger per hour. The range of average levels inside and outside bunkers is given in Table V-1. A typical chext X-ray (according to Department Health, Education, and Welfare data) might yield an exposure of abou 27,000 microRoentgens, which is equivalent to almost 900 hours of exposure to the maximum rate measured at the Seneca site (31 micro-Roentgens per hour). Background levels in the Romulus area average about 10 microRoentgens per hour.

The National Council on Radiation Protection and Measurements (NCRP) has recommended a maximum annual whole-body exposure of 500,0 microRoentgens for an individual in the general population. This va corresponds to 250 microRoentgens per hour for 2000 exposure hours (hours per week and 50 weeks per year). Thus, all external gamma exposures at the Seneca site are less than the guideline.

Inhalation of Radionuclides

As may be seen in Table V-2, radium-226 changes to radon-222 as

tration can build up in closed areas of structures. Outdoor conce trations of radon are generally lower than those inside structure Measurements made in the eleven bunkers used for uranium ore stor the site indicate concentrations of radon which range from 0.5 to picocuries[c] per liter of air. A concentration of 1.2 picocuries liter was measured inside a "background" bunker in which ore had been stored. The guideline value of 3.0 picocuries per liter, as for the general public in 10 CFR 20,[d] was exceeded in eight of th eleven bunkers. Although the measurements taken do not represent term average radon concentrations, they do indicate that exposure excess of guidelines can be expected if occupancy of the bunkers increase.

As may be seen in Table V-2, the decay of radon-222 produces of short-lived daughters. The concentration of radon daughters i the "background" bunker was 0.013 working level (WL).[e] A guideli for structures (other than dwellings or schools) used by members public is 0.03 WL given in 10 CFR 712.[f] Measurements at the Sene indicate that the concentration of radon daughters in the eleven

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[c]One picocurie is one million-millionth of a curie, previous defined.

[d]Title 10, Code of Federal Regulations, Part 20, is a regula document published by the Nuclear Regulatory Commission and may b in the Federal Register.

[e]The working level is a unit which was defined for radiation

measured in six of the eleven bunkers exceeded the 10 CFR 712 guideli
These radon daughter measurements, together with the radon concentrat
measurements, indicate that exposures in excess of guidelines can be
expected if these bunkers were to be more frequently occupied.

Studies of the health of uranium and other hard rock miners have established that inhalation of large quantities of daughters of radon 222 over long periods of time increases an individual's risk of contr lung cancer. The present federal guide value for uranium mine worker (given by the Environmental Protection Agency), when translated to th units discussed here, would limit mine workers to an exposure of 0.33 working levels, assuming exposure for 2000 hours per year, a typical work year. This level is significantly lower than the exposures recei by most of the miners included in the health studies referred to abov

Other Considerations of Exposure

Water samples taken at the site indicate no significant contamina by radionuclides. Each sample was analyzed for a variety of radionucl and the concentration of each radionuclide was well below the concentr guide in water (CG_W) as set forth in 10 CFR 20.

While no crops are currently grown on this site, use of the conta inated soil for such a purpose would produce additional human exposure through consumption of crops which have incorporated radium-226. Acti which involve considerable scraping of dry soil or contaminated bunker

Risks resulting from radiation exposures should be considered within the context of other risks incurred in normal living. For simplicity, risks to health may be classified in four categories:

1. Unacceptable – problems with risk so high as to require immediate action, such as severe diseases where medical tr ment is required to save a life.
2. Concerned – problems where people are willing to spend tim and money to reduce potential hazards. Examples of this include the maintenance of public highways and signs, sign fire departments, and rescue squads.
3. Recognized – problems where people may accept some inconve nience to avoid certain activities such as flying in airpl swimming alone, etc.
4. No great concern – problems with a low frequency of occurr There is an awareness of potential hazard, but an accompan feeling that these problems occur only to other people.

An individual may be exposed to risks over which he can exercis some control (voluntary), and risks over which he feels he has no pe control or choice (involuntary).

Daily, an individual is confronted with decisions about risk wh have an associted benefit – for example, driving a car. This can se as an illustration that a voluntary, concerned risk may be deemed appropriate due to the desirable perceived benefit. As another exam

exposure. The reasons for this are numerous; they include the individ age at onset of exposure, variability in latency period (time between exposure and physical evidence of disease), the individual's personal habits and state of health, previous or concurrent exposure to other cancer-causing agents, and the individual's family medical history. Because of these variables, large uncertainties would exist in any estimates of the number of increased cancers in the relatively small working population at the Seneca site.

The normal annual death rate[g] from lung cancer for all population groups in Seneca County (as of 1970) was 14.4 deaths per 100,000 population. At the same time, the annual death rates from lung cancer for all population groups in the United States and the state of New Yo were 21.1 and 24.2 deaths per 100,000 population, respectively. A one-year exposure to the guideline value for uranium miners (0.33 working level for 2000 hours) might increase the risk of death due to lung cancer by approximately four percent.

The annual death rate from all types of cancer among all populatio groups in Seneca County (as of 1970) was 115 deaths per 100,000 population. At the same time, the death rates from all types of cancer for all population groups in the United States and in the state of New York were 151 and 172 per 100,000 population, respectively.

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[g]Mortality statistics were obtained from data in *U.S. Cancer*

about one-tenth of a percent. Exposures in excess of these guideline values would be expected to result in proportionately higher increase in risk. Consequently, any action taken to reduce either the rate or the duration of radiation exposures would also reduce the risk attend to that exposure.

Remedial Measures

The primary pathway by which employees at the Seneca Army Depot are exposed to radiation is by inhalation of radon and its short-live daughters. These exposures occur primarly in bunkers which are conta inated as a result of uranium ore storage in the 1940's. Remedial measures could consist of thoroughly cleaning all floors, walls, ceil vents, and drains in these contaminated bunkers. Contaminated soil outside these bunkers could be removed and replaced with uncontaminat fill. Occupancy of the contaminated bunkers should remain restricted until these structures have been decontaminated. The Department of Energy is now actively evaluating these and other alternatives under priority program designed to assure public protection.

SUMMARY

Eight bunkers at the Seneca Army Depot appear to be contaminated with residues containing naturally occurring uranium-238 and radium-2 This contamination is producing radon and radon daughter concentratio

some remedial measures are in order. The Department of Energy (DOE) has developed a coordinated plan which addresses the specific problem at the Seneca site. Currently, work is underway to implement the ele of this plan.

Exposure Source	Background Levels	Guideline Value for General Public	Guideline Value for Radiation Workers	Average Romu
Radon in air	Less than one picocurie[a] per liter of air outdoors, 1.2 picocuries per liter measured inside "back-ground" bunker	Continuous exposure to 3 picocuries per liter of air	Exposure to 30 pico-curies per liter of air for 40 hours per week and 50 weeks per year	Average co ranged fro picocuries air inside for uraniu
Radon daughters in air	Less than 0.01 working level[b] out-doors, 0.013 working level measured inside "background" bunker	0.01 working level for residences and school rooms, and 0.03 working level for other structures	0.33 working level for uranium miners exposed for 40 hours per week and 50 weeks per year	Average co ranged fro ing level ing level used for u
Gamma radiation from daughters of radium and uranium con-tamination	10 micro-Roentgens[c] per hour out-doors in the Romulus area; 10 micro-Roentgens per hour measured inside "back-ground" bunker	250 microRoentgens per hour above natural background for 40 hours per week and 50 weeks per year for an individ-ual in the general public. This is equiv-alent to 0.5 Roentgen per year	2500 microRoentgens per hour for 40 hours per week and 50 weeks per year. This is equiva-lent to 5 Roentgens per year	Average g levels on the floor ranged fr microRoen average l bunkers r to 14 mic hour

[a]The picocurie is a unit which was defined for expressing the amount of radioactivity present

[b]The working level is a unit which was defined for radiation protection purposes for uranium presents a specific level of energy emitted by the short-lived daughters of radon.

[c]The Roentgen is a unit which was defined for radiation protection purposes for people expose penetrating gamma radiation. A microRoentgen is one millionth of a Roentgen.

Uranium-238 decay series

Parent	Half-life	Decay products	Dau
uranium-238	4.5 billion years	alpha	thorium
thorium-234	24 days	beta, gamma	protact
protactinium-234	1.2 minutes	beta, gamma	uranium
uranium-234	250 thousand years	alpha	thorium
thorium-230	80 thousand years	alpha	radium-
radium-226	1600 years	alpha	radon-2
radon-222	3.8 days	alpha	poloniu
polonium-218*	3 minutes	alpha	lead-21
lead-214*	27 minutes	beta, gamma	bismuth-
bismuth-214*	20 minutes	beta, gamma	polonium
polonium-214*	$\frac{2}{10,000}$ second	alpha	lead-21
lead-210	22 years	beta	bismuth-
bismuth-210	5 days	beta	polonium
polonium-210	140 days	alpha	lead-206
lead-206	stable	none	none

*Short-lived radon daughters.